



Lightweight Crypto in Reverse

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Motivation

Why is reversible computing cool?

Question:

What is the universe going to look like in 10^{40} years?

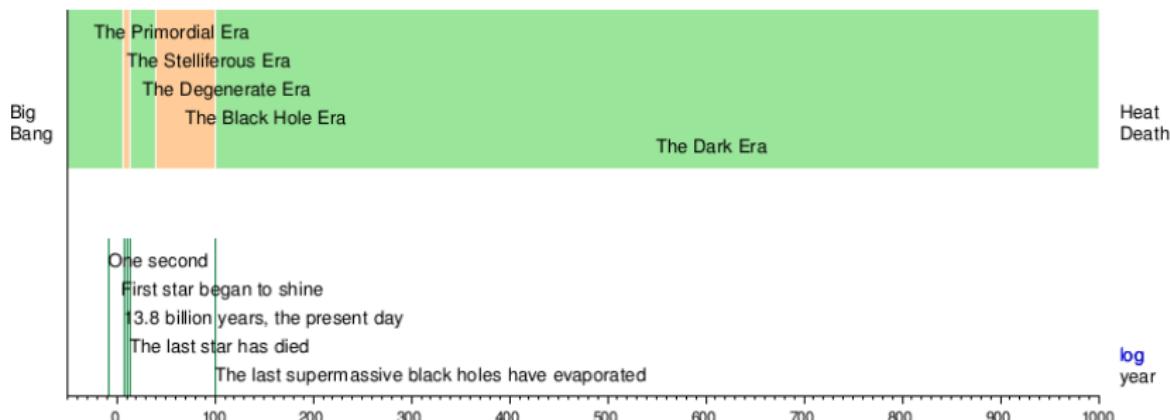


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Source: Wikipedia
(Proton decay is a different problem.)



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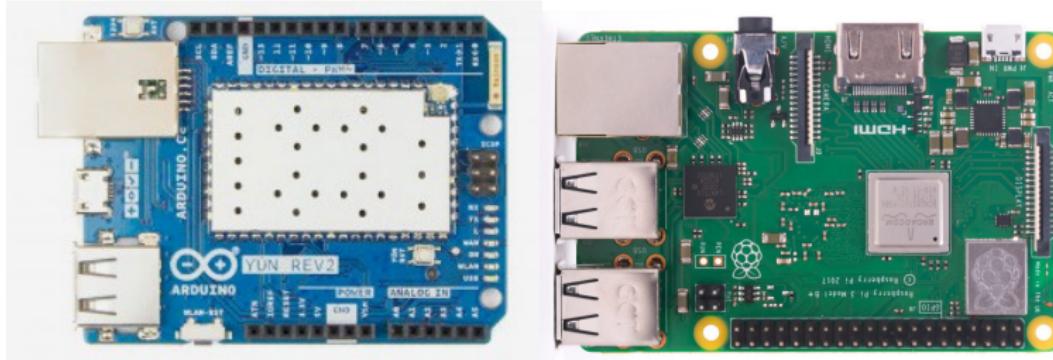
Why is lightweight cryptography cool?

Applications

IoT and related: small systems with limited power (in any sense).

Simplicity

Mostly only symmetric cryptography, simpler and more efficient algorithms.



Source: Arduino & Raspberry Pi



Lightweight Cryptography and Reversible Computation



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Low-power devices should also eventually take advantage of the low-power consumption implication of reversibility.



Bijective Functions

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For any bijective function, there exists its inverse bijection.

With reversible code, we obtain the inverse function by reversing (inverting) the code.



Symmetric Cryptography

Duality

Symmetric and crypto functions are bijective functions with a clear encryption/decryption duality.

I/O

Input and output are similar with having at least two parameters: the key and the plaintext or ciphertext.

$$\llbracket \text{enc} \rrbracket(k, p) = (k, c)$$

$$\llbracket \text{dec} \rrbracket(k, c) = \llbracket \mathcal{I}(\text{enc}) \rrbracket(k, c) = (k, p).$$



Side channel vulnerabilities

Algorithm's mathematical strength is one part of the security, its implementation is another.



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Algorithm's mathematical strength is one part of the security, its implementation is another.

Implementation can be just as hard, especially when the programmers have to actively fight the compilers.

State information leakage, timing differences, power consumption, EM radiation, noise, etc.



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What are we trying to achieve?

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Have we reached them? Yes!



Avoiding state leakage

Goal #1



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Reversible code cannot erase information.

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- Memory cannot be reset and is assumed to be zero.
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The computational state information is only temporary, stored within local variables.



Example

Goal #1

```
procedure TEA_encipher(u32 data[], u32 key[])
    local u32 delta = 2654435769
    local u32 sum = 0
    iterate int i = 1 by 1 to 32
        sum += delta
        data[0] += ((data[1] * 16) + key[0]) ^
                    (data[1] + sum) ^
                    ((data[1] / 32) + key[1])
        data[1] += ((data[0] * 16) + key[2]) ^
                    (data[0] + sum) ^
                    ((data[0] / 32) + key[3])
    end
    delocal u32 sum = 32*delta
    delocal u32 delta =2654435769
```



Simplifying programming work

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Implementing just encryption (or just decryption) is sufficient. The other function is simply its interpretation in reverse.



Simplifying programming work

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Encryption is bijection

Implementing just encryption (or just decryption) is sufficient. The other function is simply its interpretation in reverse.

Saves time on:

- ① Writing the inverse function code
- ② Testing for its correctness and its inverseness to the other function
- ③ Debugging



Example

Goal #2

```
show(data)
call TEA_encipher(data, key)
show(data)
uncall TEA_encipher(data, key)
show(data)
```

```
data[2] = {42, 27}
data[2] = {1535266570, 1744185122}
data[2] = {42, 27}
```



Learning and improving Janus

Goal #3

Learning

- Implemented several crypto algorithms in Janus
- Re-discovered both Bennett's tricks

Improving

- Fixed bugs in Jana
- Made improvements to Jana
- Suggested two Janus extensions



Example

Goal #3

```
// z1 = y1 ^ ((y0 +y3) <<< 7)
tmp += seq[0] + seq[3]
call rotate_left_u32(tmp, 7)
seq[1] ^= tmp
uncall rotate_left_u32(tmp, 7)
tmp -= (seq[0] + seq[3])
```

```
// z1 = y1 ^ ((y0 +y3) <<< 7)
seq[1] ^= call rotate_left_u32(seq[0] +seq[3], 7)
```



Experiment

Evaluating the first goal

- ① Examining leakage in both reference and our implementations
- ② Evaluating alternatives



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Evaluating the first goal

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-
- ① Secretgrind
 - ② Vale, zerostack



Examining leakage

```
***(1) (stack)    range [0xffefffd40 - 0xffefffdff]
      (192 bytes) is tainted
Total bytes tainted: 192

***(1) (stack)    range [0xffefffdc0 - 0xffefffdff] (64
      bytes) is tainted
> (stack) [0xffefffdc0 - 0xffefffdc3] (4 bytes):
  Chacha20.janus.3.cpp:702:@0xffefffdc0:seq
  ...
> (stack) [0xffefffdc4 - 0xffefffdc7] (4 bytes):
  Chacha20.janus.3.cpp:702:@0xffefffdc4:seq[1]
  ...
> (stack) [0xffefffdc8 - 0xffefffdff] (56 bytes):
  Chacha20.janus.3.cpp:702:@0xffefffdc0:seq
  ...
Total bytes tainted: 64
```



Evaluating alternatives

Vale

- Not mature enough
- Problematic to set up
- Very broad to understand
- Difficult to use
- Limited documentation
- Huge potential

zerostack

- Much easier to set up
- Extremely simple to understand and use
- Documentation unnecessary due to simplicity
- Not mature (supports only single configuration)
- Limited potential



Contributions

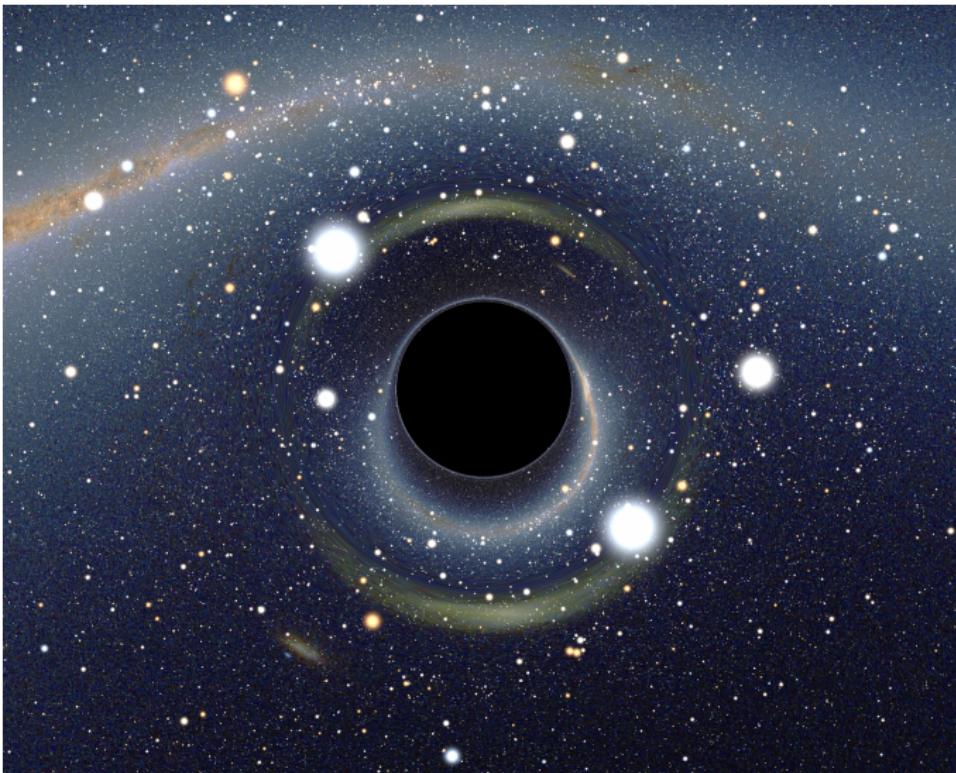
- ① Shown usefulness of reversibility in cryptography
- ② Implemented several cryptographic algorithms
- ③ Improved Janus and Jana
- ④ Research published in LNCS
- ⑤ All work available on GitHub



Main contribution



Main contribution



Source: Wikipedia



That's it!

Thank you!
Questions?

