Stream ciphers
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However,

we are right, and they are wrong.
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- As we defined them, PRGs are limited
  - They have fixed-length output
  - They produce output in “one shot”
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- In practice, Psuedo 1-Time Pads use Stream Ciphers
  - Can be viewed as producing an “infinite” stream of pseudorandom bits, on demand
  - More flexible, more efficient
A **Stream Cipher** is basically a *recurrence* that generates bits. Formally a **Stream Cipher** is a pair of efficient, deterministic algorithms (Init, GetBits) such that:

1. Init does the following:
   1.1 **Input** private seed $s$. Think of as truly random.
   1.2 **Output** $y_0, y_1, \ldots, y_n$ for some $n$. 

2. GetBits does the following:
   2.1 Input Given $y_0, \ldots, y_m$ (likely depends on less of the past).
   2.2 Output the bit $y_{m+1}$. 

Note: In practice, $y_i$ is a block rather than a bit.
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- Can use (Init, GetBits) to generate any desired number of output bits from an initial seed
Stream ciphers

- A stream cipher is **secure** (informally) if the output stream generated from a uniform seed is pseudorandom
  - I.e. regardless of how long the output stream is (so long as it is polynomial)
  - We omit formal definition which is in terms of games.
Do Stream Ciphers exist? Theoretical

Under reasonable crypto assumptions can construct Secure Stream Cipher.
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Over time, constructions that are too slow are worked on and become fast enough.
Do Stream Ciphers exist? Practical

Attempts at Stream Ciphers:

1. Linear Feedback Shift Registers. Fast! Used! Not Secure!

Note
Seems impossible to get Stream Ciphers that are provably (even using Hardness Assumptions) secure and practical.

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But having the rigor gives the practitioners (1) a target to shoot for, and (2) pitfalls to watch out for.
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Linear Feedback Shift Registers (LFSR): Example

Degree 3 LFSR, 3 constants: \( c_3, c_2, c_1 \in \{0, 1\} \). + is mod 2.

Key is 3 bits: \((y_0, y_1, y_2)\).
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Key is 3 bits: \((y_0, y_1, y_2)\).

\[(\forall t \geq 3)[y_t = c_1 y_{t-1} + c_2 y_{t-2} + c_3 y_{t-3}].\]

**Note** Leave it to you to generalize to degree \(n\) LFSR.
LFSRs

1. Will eventually be periodic but hope the periodicity is long.
2. For $n$-degree max periodicity is $2^n - 1$.
3. Known how to set feedback coefficients so as to achieve $2^n - 1$.
4. Maximal-length LFSRs have good statistical properties.
5. Are LFSRs secure? Vote YES, NO, UNKNOWN TO SCIENCE.

NO.
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Example of Bad Security

Degree 3. $c_0, c_1, c_2$ unknown. If $y_1, y_2, y_3, y_4, y_5, y_6$ become known then:

$$y_4 = c_2 y_3 + c_1 y_2 + c_0 y_1$$
$$y_5 = c_2 y_4 + c_1 y_3 + c_0 y_2$$
$$y_6 = c_2 y_5 + c_1 y_4 + c_0 y_3$$

3 linear equations in 3 variables. Can find $c_0, c_1, c_2$.

Cracked!

For $n$-degree LFSR can crack after $2^n$ iterations.

Moral: Linearity is bad cryptography.
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LFSR and Linearity

Linearity makes LFSR’s fast

Linearity makes LFSR’s crackable
LFSR and Linearity

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Who first said:

Those who lives by linearity, dies by linearity!
Linearity makes LFSR’s *fast*

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Who first said:

*Those who lives by linearity, dies by linearity!*

It was Irene!
Recall: The Essence of Crypto is to make computation
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1. Easy for Alice and Bob.
The Essence of Crypto

**Recall:** The Essence of Crypto is to make computation

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Recall: The Essence of Crypto is to make computation

1. Easy for Alice and Bob.
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LFSR makes computation easy for all three!
Nonlinear Feedback Shift Registers (NFSRs)

1. Add nonlinearity to prevent attacks
2. Nonlinear feedback
3. Output is a nonlinear function of the state
4. Multiple (coupled) LFSRs
5. . . . or any combination of the above
6. Still want to preserve statistical properties of the output, and long cycle length
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Nonlinear Feedback Shift Registers

Assume \( n \) even. \( + \) is mod 2.
Initialize with \( x_1, x_2, x_3, x_4 \)
\((\forall n \geq 5)[x_n = x_{n−1}x_{n−2} + x_{n−2}x_{n−3} + x_{n−3}x_{n−4}]\).
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Is this a good stream cipher? Vote Y (with HA), N, UN
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UNKNOWN
I made up this cipher last year for example of nonlinear.
On the HW you will tell me if its a good stream cipher.
Trivum
Trivium

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- Intended to be simple and efficient (especially in hardware).
- Essentially no attacks better than brute-force search are known.
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- Three coupled Feedback Shift Registers (FSR) of degree 93, 84, and 111.

- Initialization:
  - 80-bit key in left-most registers of first FSR. This is private.
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  - Run for $4 \times 288$ clock ticks to finish init.
Trivium-Initialization

K_1, \ldots, K_{80}

Random \ IV_1, \ldots, IV_{80}

(a_1, \ldots, a_{93}) \leftarrow (K_1, \ldots, K_{80}, 0, \ldots, 0)

(b_1, \ldots, b_{84}) \leftarrow (IV_1, \ldots, IV_{80}, 0, 0, 0, 0)

(c_1, \ldots, c_{111}) \leftarrow (0, \ldots, 0, 1, 1, 1)

For i = 1 to 4 \times 288 do

1. t_1 \leftarrow a_{86} + a_{91} + a_{92} + b_{79}

2. t_2 \leftarrow b_{70} + b_{83} + b_{84} + c_1 + c_{87}

3. t_3 \leftarrow c_{66} + c_{100} + c_{110} + c_{111} + a_{69}

4. (a_1, \ldots, a_{93}) \leftarrow (t_3, a_1, \ldots, a_{92})

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Note

No random bits output. This is just initialization.
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Trivium-Iteration

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For $i = 1$ to $\infty$ do
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For \( i = 1 \) to \( \infty \) do

1. \( y_i = a_{66} + a_{93} + b_{70} + b_{75} + c_{66} + c_{111} \) (\( i \)th random bit).
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Trivium-Iteration

We omit superscripts for readability.
For $i = 1$ to $\infty$ do

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Note the three diff parts of $s$ are three coupled nonlinear FSR.
Trivium based on LFSR though not LFSR

Note:
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Since $t_1, t_2, t_3$ nonlinear, Trivium is NOT LFSR
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Benefit: Shifting is Fast!
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1) Has been built in hardware with 3488 logic gates. Small! Fast!
2) So far has not been broken. That we know of!
3) Naive method is $2^{80}$ steps. Guess all keys.
4) If only do $\sim 700$ init steps then Cube Attack is $2^{68}$ steps.
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*The word trivium is Latin for the three-fold way, and refers to the three-fold symmetry of TRIVIUM. The adjective trivial which was derived from it, has a connotation of simplicity, which is also one of the characteristics of TRIVIUM.*
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This Fall I am teaching the senior course in Crypto at UMCP. Its a nice change of pace for me since REAL people REALLY use this stuff!

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First Comment on Blog

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Too bad. They called my post Great.
An 80-bit key/IV is not secure enough for many modern uses (like encryption on the Internet), though I am not sure what exactly Trivium and other "lightweight ciphers" consider a threat. Their primary intended deployment scenarios are IoT and hardware tokens like auto door locks. For that purpose it is secure.
Salsa20 Stream Cipher

**Notation:** $\oplus$ is the usual bit-wise XOR. $+$ is mod $2^{32}$ addition. $<<<$ will mean you circular shift bits to the left.

Note: $\oplus$ and $+$ and $<<<$ are fast! So $QR(a, b, c, d)$ is fast.

Note: Scrambles up $a$, $b$, $c$, $d$ a lot!
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**Basic Operation:** On input four words $(a, b, c, d)$, $QR(a, b, c, d)$ is

\[
\begin{align*}
\text{QR}(a, b, c, d) &= (a \oplus (c + d)) \lll 18 \\
&= (b \oplus (b + d)) \lll 7 \\
&= (c \oplus (a + b)) \lll 9 \\
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Salsa20 Stream Cipher-Init

Initially have a 4×4 array of bytes (8 bits).

Const Key

Const nonce

Const Pos

View as 8 words by reading up-down, left-right

Const:

Constants that are standardized. Public

Key:

Known only to Alice and Bob, used for long time. Private.

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Salsa20 Stream Cipher-Init and other Issues

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**How Many Rounds:** Salsa20 sets it to 20. Duh.
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How Many Rounds: Salsa20 sets it to 20. Duh.
We now have a well mixed $4 \times 4$ array of bytes (8 bits).
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**Salsa20 Stream Cipher-GetBits**

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**No!** All steps are reversible. From that array one can work backwards and find the Key!
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Just one more step:

Let the $4 \times 4$ array be $x[0], \ldots, x[15]$. 
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Let the $4 \times 4$ initial array be $in[0], \ldots, in[15]$.

Security: Salsa20 was introduced in 2005 and has not been broken. See Wikipedia page for partial attacks (e.g., Salsa8).
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*Absent proofs, the only ways to claim that a stream cipher is good are to (1) follow known design principles and (2) make sure known attacks do not work. It helps lend credibility if they are designed by people who know what they are doing, not just throwing random stuff together, but I realize that’s not very scientific.*
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*Trivium, in particular, always struck me as so simple that it cannot possibly be secure. And yet, there are no attacks. But I don’t think it has been subject to the same scrutiny as AES, or even RC4. ChaCha is actually used, so people care about its security. Hence its security seems solid. For now.*
Good Science and Bad Science

**Karl Popper (1930’s):** A Scientific Theory should be **falsifiable**. Propose experiments that could show it is **not** true. The longer the theory survives scrutiny the more likely it is to be true.

1) **Classical Mechanics:** Good Science. Many experiments proposed and carried out. Confirmed it until had problems with fast speeds and small particles.

2) **Quantum Mechanics:** Good Science. Many experiments proposed and carried out. So far has not been falsified. Yet.

3) **Libertarianism Theory:** Bad Science: Everything bad is the government’s fault w/o looking at data. Global warming require government action, hence its false.

4) **Communism:** Bad Science: Wages go down – Capitalists exploiting the worker. Wages up – Capitalists placating the worker to avoid revolution.
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Speculation: Does the NSA let outsiders try to break their systems? If not then might not be Good Crypto. I really do not know. I tried asking them but they wouldn't tell me!
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