SHIFTS AND ROTATES

Shifts and rotates are fundamental operations in low-level programming and are incredibly important for anyone delving into reverse engineering or malware analysis.

They're the silent workhorses behind many **optimizations**, **obfuscations**, and even **cryptographic routines.** Let's break them down in detail.

🌀 Shifts and Rotates: Manipulating Bits with Precision

When you're working in assembly or low-level C, you **don't loop to multiply, you shift.**

You *don't call fancy functions to rotate bits*, you **ROL/ROR** like a digital warrior.
Let's break it down crystal clear:

At their core, shifts and rotates are operations that directly manipulate the individual bits within a binary value.

Think of them as **specialized tools** for rearranging the 0s and 1s that make up your data.

Understanding how they work is like **learning the secret language of processors** and the clever tricks malware authors use.

1. Shift Operations: Moving Bits In and Out

A **shift operation** involves moving all the bits of a binary value either to the left or to the right by a specified number of positions. Bits that move off one end are discarded, and new bits are introduced on the other end.

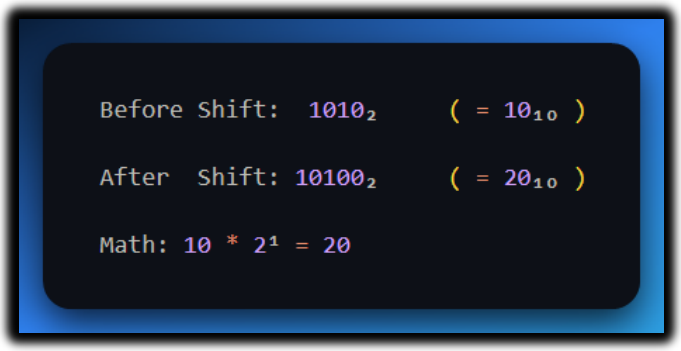
1.1. Left Shift (<<)

Concept: Imagine a line of people (bits). When you left-shift, everyone takes a step to their left. The person at the far left (most significant bit) falls off the line, and a new person, a zero (0) joins at the far right (least significant bit).

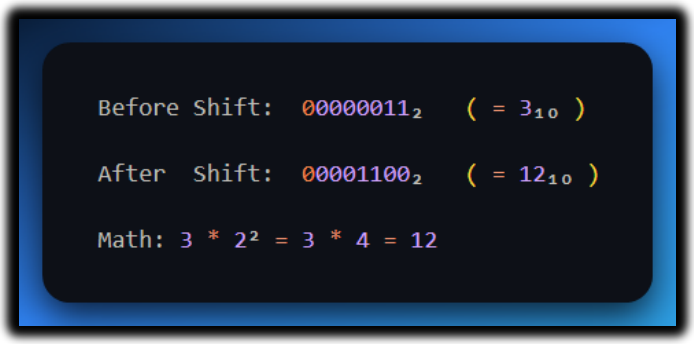
How it Works: Bits move to the left. The leftmost bit(s) are discarded. The rightmost bit(s) are filled with zeros.

Effect on Value: Shifting a binary value left by N positions is equivalent to **multiplying** that value by 2N.

Example 1: Shift 1010_2 (decimal 10) left by 1 position.



Example 2: Shift 00000011_2 (decimal 3) left by 2 positions.



😳 But wait... Why Didn't Bits Fall Off when we shifted 1010?

That's a golden question — let's clear this up:

Do bits fall off when you do a **left shift**?

✅ **Yes**, but **only** if the shifted result is too big to fit inside the register you're using (e.g., 8-bit, 16-bit, 32-bit).

But here's the key: If your original number is something like 1010 (which is 4 bits), and you're working in an 8-bit register, then you've still got room to grow.

🧪 Example:

- You start with 00001010 (8-bit version of 1010)
- Shift left by 2 → 00101000
- Still 8 bits — so nothing falls off

➡ No bits lost.

Now, let's say you had this:

- *Start with 11001010*
- *Shift left by 2 → 00101000*

The two leftmost bits (11) just **fall off the edge** and disappear.
Because 8-bit register can't hold more than 8 bits.

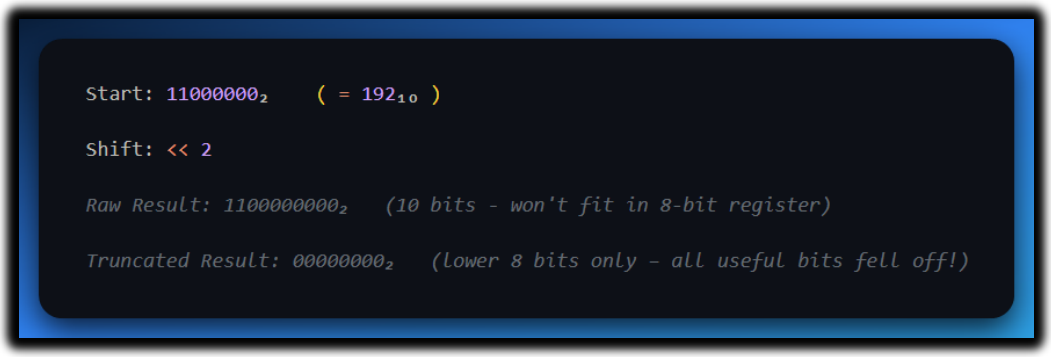
TLDR:

Shifting doesn't care **how full** your number *looks* —
It only cares about the size of the register.
Bits only "fall off" when the result **overflows** that size. Otherwise, it's just moving around inside the space.

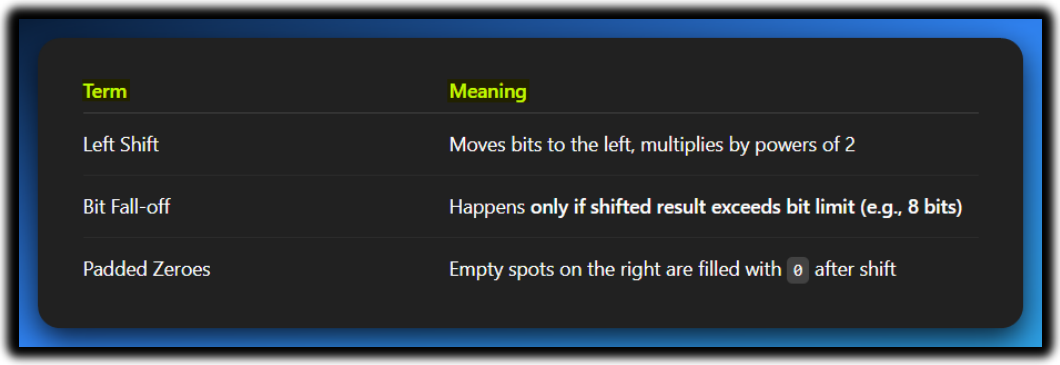
👄 Example with Bit Loss (Overflow)

Let's force a fall-off using an 8-bit register:

Shift 11000000_2 (decimal 192) left by 2

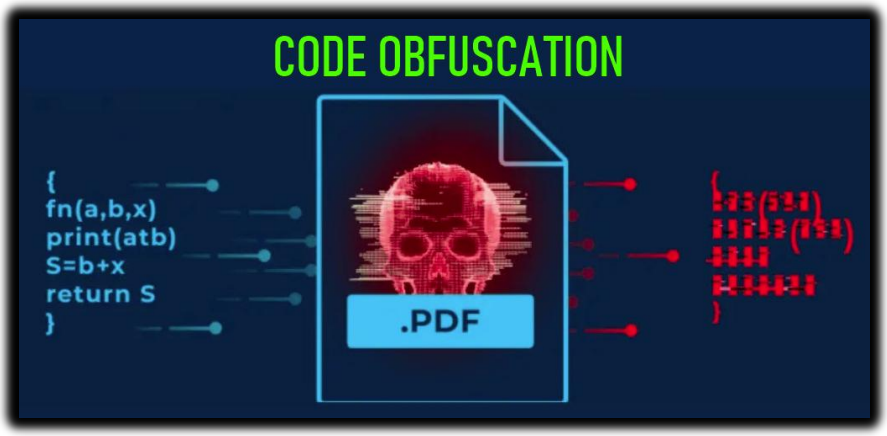


So yeah — **bits fall off only when there's no room** to keep them after the shift.



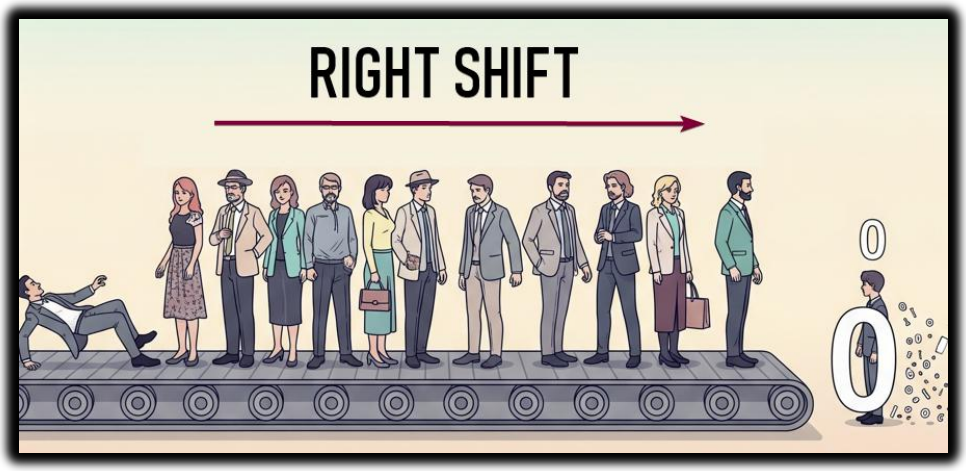
Reverse Engineering/Malware Context:

- **Fast Multiplication:** Compilers often replace multiplications by powers of 2 with left shifts because they are significantly faster for the CPU.
- **Bit Packing:** Used to quickly move bits into higher positions when assembling larger values from smaller components.
- **Obfuscation:** Can be part of simple arithmetic obfuscation to hide true values.



1.2. Right Shift (>>)

Concept: Now, everyone takes a step to their right. The person at the far right (least significant bit) falls off the treadmill, and a new person joins at the far left (most significant bit). The crucial part here is *who* joins at the left.

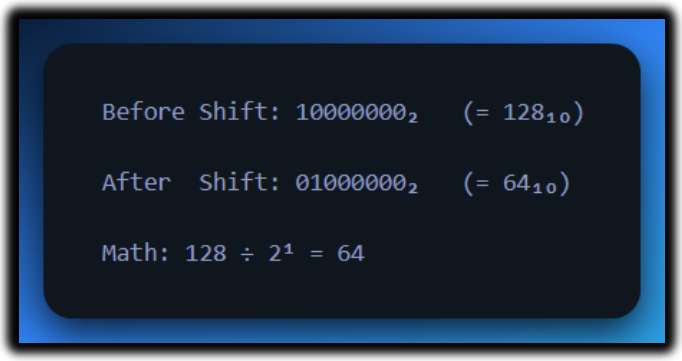


How it Works: Bits move to the right. The rightmost bit(s) are discarded. The leftmost bit(s) are filled based on the type of right shift:

1. Logical Right Shift (LSR):

Fills the leftmost bits with 0s. This is typically used for **unsigned numbers**.

Shift 10000000_2 (128) right by 1:



2. Arithmetic Right Shift (ASR):

Fills the leftmost bits with the value of the **original Most Significant Bit (MSB)**. This preserves the sign of the number and is typically used for **signed numbers**.

- ASR shifts the bits to the **right**, like a normal right shift.
- But the **leftmost bit (MSB)** — which is the **sign bit** in two's complement — is **copied** to fill in the blank spots on the left.
- This preserves whether the number was **positive or negative** after the shift.

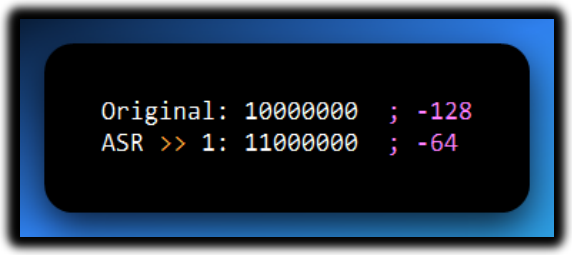
We discuss this in depth on the next section. Keep reading ⚡

🔍 Why Is ASR Important?

- In signed binary numbers (two's complement), **1 in the MSB** means the number is **negative**.
- If you just shoved in 0s during a right shift, you'd change a negative number into a positive — which is **completely wrong**.
- So, we **extend the sign** using the MSB during the shift — that's called **sign extension**.

🔢 Example 1: Shifting a Negative Number

Let's take **-128** in 8-bit two's complement:

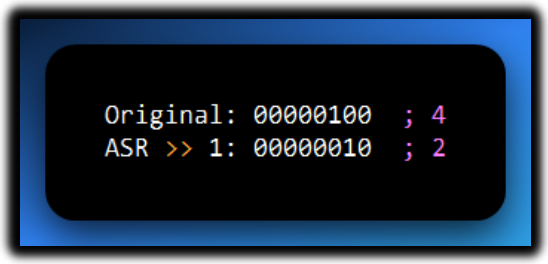


Step-by-step:

1. The 1 at the MSB (sign bit) says this number is negative.
2. ASR shifts everything right one place.
3. The new bit that comes in on the left is also a 1 (copied from the MSB).
4. The number remains **negative** — now it's -64.

🧠 If we used **logical shift** (fill with 0), we'd get 01000000 → **+64**, which is **wrong**.

🔢 Example 2: Shifting a Positive Number



Since the MSB is 0, the shift just fills with 0s — same as logical right shift.

✅ Key Concept: Divide by Powers of Two

Arithmetic right shift **divides a signed number by 2^n**, using integer division:

Binary	Decimal	ASR >> 1	Result
11111110	-2	11111111	-1
10000000	-128	11000000	-64
00001000	8	00000100	4
00000101	5	00000010	2 (floor of 2.5)

Here are the three key uses of the Arithmetic Right Shift (ASR) in a reverse engineering, malware, or hacking context, explained in simple sentences:

- **Fast Division:** ASR is used for very quick division of signed numbers by powers of two, as it's much faster than traditional division operations.
- **Bit Field Extraction:** It helps you isolate and grab specific groups of bits or flags from a larger value, discarding the rest.
- **Sign Preservation:** ASR is crucial for maintaining the correct positive or negative sign of a number when you're manipulating its bits or extending it to a larger size.

🔧 Assembly Tip:

Operation	Instruction
Logical Right	SHR
Arithmetic Right	SAR
Signed? Use SAR	✅
Unsigned? Use SHR	✅

SHIFTS AND ROTATES: THE COMPLETE BIT MANIPULATION TOOLKIT PART 2

⚡ Heads-Up for All Reverse Engineers:

When you're digging through disassembly in **Ghidra**, **IDA**, or **Binary Ninja** — **watch for these ops:**
SHL, SHR, SAL, SAR, ROL, ROR, RCL, RCR

⚡ Why?

Because these are **not just random instructions** — they're **bit surgeons**.
They cut, flip, and rotate bits inside registers like pros. If you don't know what they're doing, you're missing the *plot twist* in the code.

⚡ Real Talk:

These are the tools that low-level code uses to:

- Mix up values.
- Encrypt stuff.
- Parse flags.
- Hide secrets.
- Trick analysis tools.

All of it — **through just bits**.

🧠 Get this deep in your brain:

Shifts and rotates **are the gears turning inside the CPU**.
They're not fancy, but they're **everywhere** — and once you get them,
you start seeing the **actual logic** behind compiled code, not just machine gibberish.

📣 Repeating this louder for the beginners in the back:

If you don't understand how SHL or ROR and the rest works, you're flying blind.
But once you do?
You're reading **the machine's native language**. You're dangerous now. 😤

📜 The Bitwise Crew Crooks: Official Names vs Nicknames

💻 Opcode	🧠 Official Name	🕶️ Nicknames / Aliases	🔎 Used For
SHL	Shift Logical Left	Left Shift, LSH, SLL (MIPS), `<<` in C	Multiply by 2, bit masking
SAL	Shift Arithmetic Left	Same as SHL (they're literally identical on x86)	Same stuff — CPU treats them the same
SHR	Shift Logical Right	Right Shift, LSR (Logical Shift Right), `>>` (unsigned in C)	Divide by 2, clean bit slicing
SAR	Shift Arithmetic Right	Signed Right Shift, ASR (Arithmetic Shift Right)	Keeps the sign bit (for signed division)
ROL	Rotate Left	Left Rotate, Circular Left Shift	Cryptography, bit mixing
ROR	Rotate Right	Right Rotate, Circular Right Shift	Crypto, obfuscation
RCL	Rotate through Carry Left	Rotate Left w/ Carry	Obfuscation, crypto, trick debugging
RCR	Rotate through Carry Right	Rotate Right w/ Carry	Same stuff, different direction

⚠️ Why So Many Names?!

- Different **CPU architectures** = different mnemonics (MIPS, ARM, x86, etc.)
- Different **languages** = different syntax (<<, >>, etc.)
- Some just **sound cooler** (you gonna say "Rotate through carry" or just "RCL" like a pro?)

🧠 Memory Tip:

If it **has "Shift"** in the name, it probably drops bits.
If it **has "Rotate"**, it's playing hot potato with bits — nothing gets lost.
If it has **"Arithmetic"**, it's being sensitive about signs 😭

1. Shift Operations: Bits In, Bits Out (The Conveyor Belt)

Shift operations move bits to the left or right. Bits falling off one end are lost, and new bits are introduced on the other. The key distinction is how the empty positions are filled.

We won't repeat left shifts. Simple stuff. But for right shifts, lets give it another spin, coz there's two versions.

🫣 1.1. Left Shifts?

Just SHL or SAL (they're the same instruction).

SHL (Shift Logical Left) and SAL (Shift Arithmetic Left) instructions are **literally the exact same instruction** on most modern CPUs.

Nothing fancy — just push bits left and pad the right with zeros. Done.
💡 **Easy = no need to repeat.**

Since the operation for both **"logical"** and **"arithmetic"** left shifts would involve bringing in zeros from the right, and the **sign bit doesn't require special handling** to maintain arithmetic correctness during a left shift (it just moves), **there's no practical difference in their execution**.

They perform the **exact same bit manipulation.** The CPU designers effectively merged them into one operation with two mnemonics for clarity or historical reasons.

1.2. Right Shifts

Logical Right Shift (SHR - Shift Logical Right):

Every bit moves one position to the right. The bit that "falls off" the least significant (rightmost) end goes into the **Carry Flag (CF)**. The most significant (leftmost) bit is filled with a 0.

Effect: Equivalent to unsigned division by 2N.

Example (8-bit):

Initial State of the 8-bit register is 10101010_2 (170 decimal), and we're performing a SHR 1 no need for carry flag here.

Shifted everyone moves one step to the right. The LSB gets banned, falls off and we introduce a new MSB ninja, 0 to replace the fallen one, and this results to 01010101_2 (85), CF = irrelevant here.

Use Case: Primarily for unsigned integer division.

Arithmetic Right Shift (SAR - Shift Arithmetic Right):

Concept: Every bit moves one position to the right. The bit that "falls off" the least significant (rightmost) end goes into the **Carry Flag (CF)**. The most significant (leftmost)

bit is filled with a copy of the **original MSB (sign bit)**. This preserves the sign of the number.

Effect: Equivalent to signed integer division by 2N.

Example (8-bit, positive): 00001010_2 (10) SAR 1 CF <- 0 00000101_2 (5), CF = 0

Example (8-bit, negative): 11111010_2 (-6) SAR 1 CF <- 0 11111101_2 (-3), CF = 0 (original MSB was 1, so 1 is copied)

Use Case: For signed integer division.

2. Rotate Operations: The Circular Dance (Bits Never Die!)

Rotate operations move bits around a circular path. Bits shifted out from one end are re-inserted at the other end. No bits are lost or introduced.

2.1. Simple Rotates (Without Carry Flag)

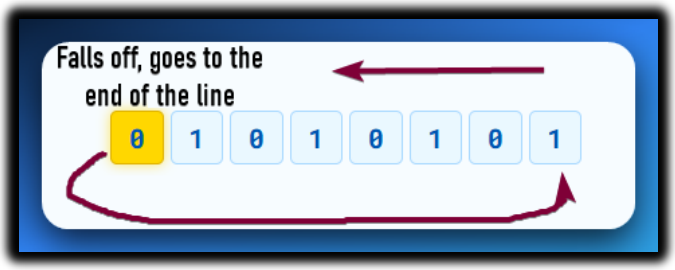
🔄 Rotate Left (ROL)

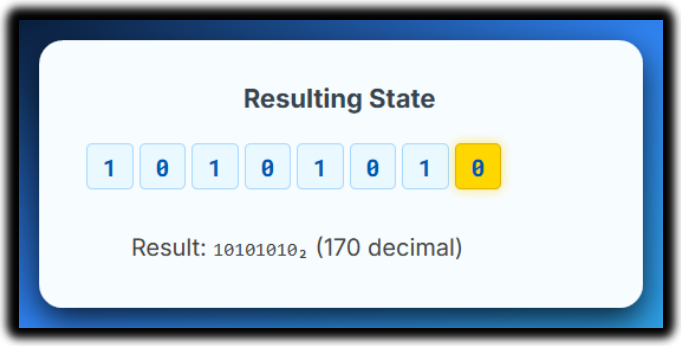
Shifts all bits to the left. The leftmost bit (MSB) *wraps around* to the rightmost bit (LSB), like a conveyor belt. Also, the original MSB gets saved in the Carry Flag (CF) — like a side note for the CPU.

Example (8-bit):

Initial register value was 01010101_2 (85) and we're doing a ROL 1 no need for a CF here.

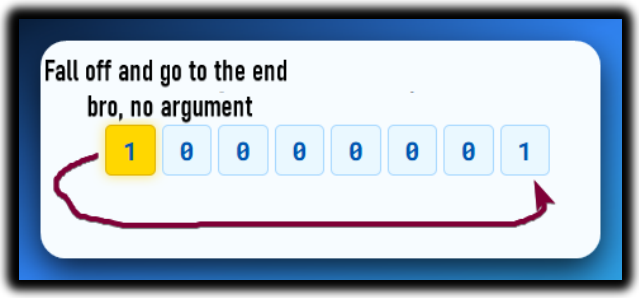
Original MSB 0, wraps to LSB. Result: 10101010_2 (170), CF = 0





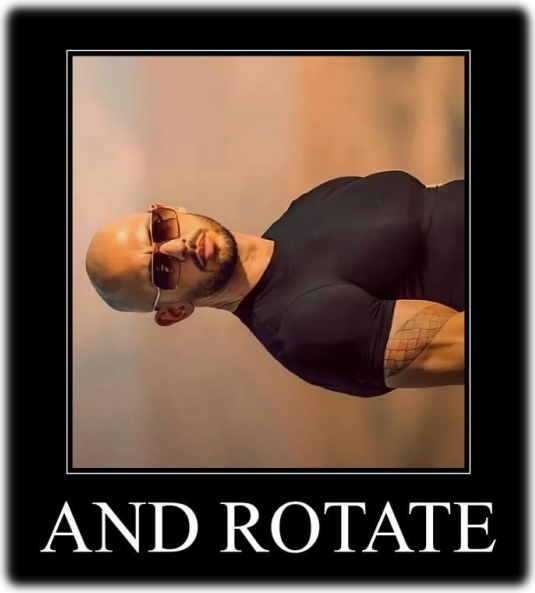
Example (8-bit):

Initial register holds 10000001_2 (129) we are performing a ROL 1, carry flag is not being used at all so we leave it as **?**



Original MSB goes and becomes the LSB (Least Significant Bit) resulting in 00000011_2 (3) and **no bits are lost.**

I need this space gone:



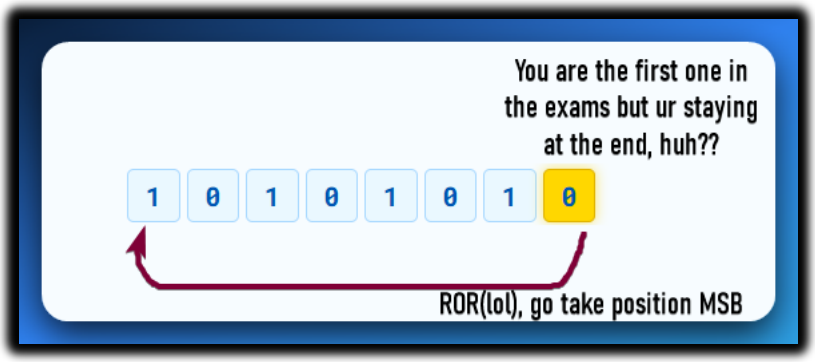
🔄 Rotate Right (ROR - Rotate Right):

The bits shift right, and the bit that "falls off" the LSB end wraps around and becomes the new MSB. The original LSB also goes into the **Carry Flag (CF)**.

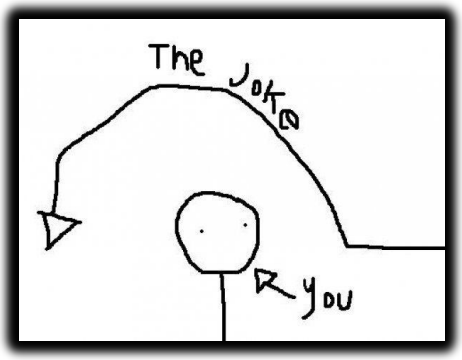
Example (8-bit):

Initial State: Register = 10101010_2 (170 decimal) and we're performing a ROR 1 and it has not Carry Flag, just like the Rotate Left.

Original LSB 0 wraps to MSB. This Results to 01010101_2 (85), CF = 0

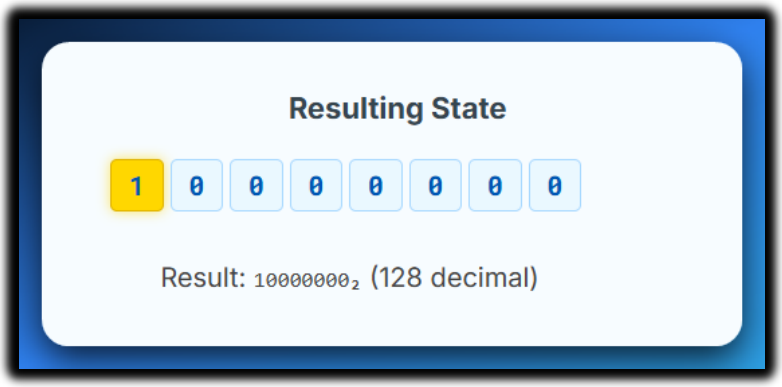


If you didn't see the joke, you're not reading this book the right way… 💀



Example (8-bit):

Initial register state is 00000001_2 (1 decimal) and we're performing a Rotate Right, ROR 1, no Carry Flags here.



2.2. Rotates Through Carry (Including the Carry Flag!)

These are particularly interesting because they involve the CPU's **Carry Flag (CF)** as an extra bit in the rotation. This effectively makes the rotation operate on N+1 bits (where N is the size of the operand, e.g., 8, 16, 32, 64 bits).

Rotate Left Through Carry (RCL - Rotate Through Carry Left):

Concept: The bits shift left. The bit that "falls off" the MSB end goes into the **Carry Flag (CF)**. Simultaneously, the **original value of the Carry Flag** is inserted into the LSB position. It's like a circular shift involving the register and the Carry Flag as a single, larger bit string.

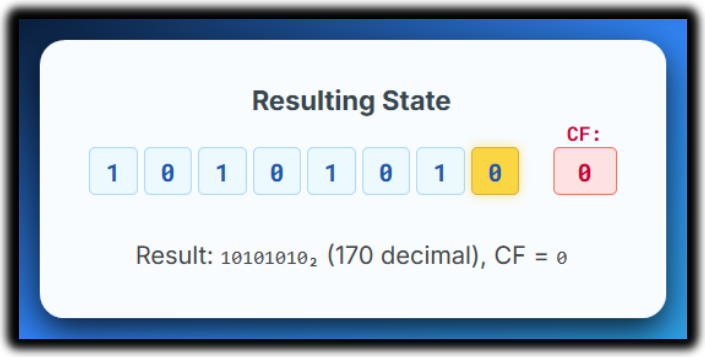
Example (8-bit, CF=0):

Initial state of the register is 01010101_2 (85), the carry flag is 0 and we're doing RCL 1.

So, when we say rotate left by carry, we mean, go and stand at the left most side of the 8 bits, that's where the MSB with 0 is.

Then tell everyone in the line to move one step to the left.

MSB (0) moves into the carry flag (CF). Original Carry Flag value (0), moves to LSB.

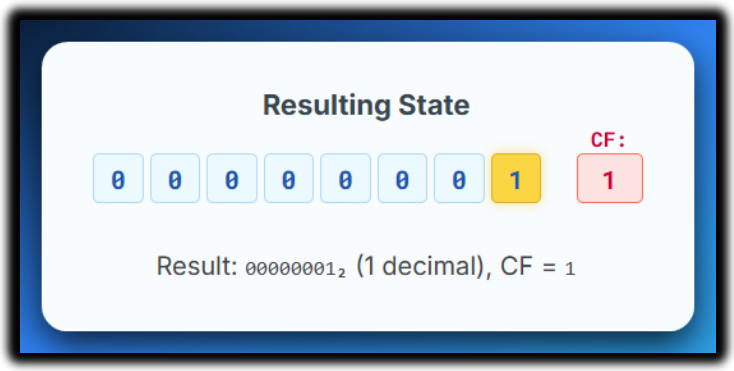


Example (8-bit, CF=1):

Initial state of the register is 10000000_2 (128), the Carry Flag is 1 and we're doing RCL 1.

MSB (Most Significant Bit) with the value (1) moves into the Carry Flag.

Original Carry Flag which had the value (1) moves to LSB (Least Significant Bit).



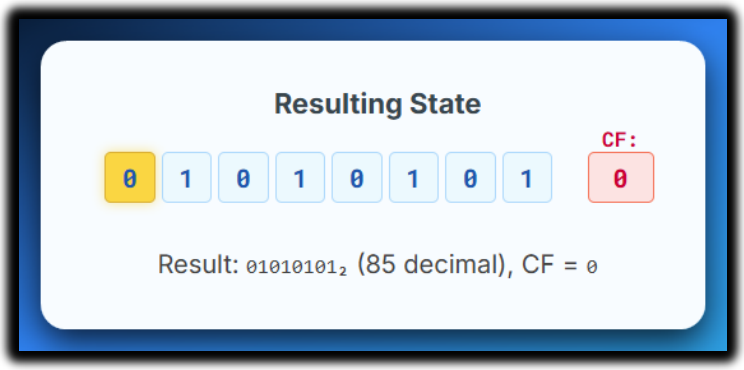
Rotate Right Through Carry (RCR - Rotate Through Carry Right):

The bits shift right. The bit that "falls off" the LSB end goes into the **Carry Flag (CF)**. Simultaneously, the **original value of the Carry Flag** is inserted into the MSB position.

Example (8-bit, CF=0):

The initial state of the register is 10101010_2 (170), the Carry Flag CF=0 and we're performing a RCR 1.

LSB (0) moves to Carry Flag. Original Carry Flag (0) moves to MSB.

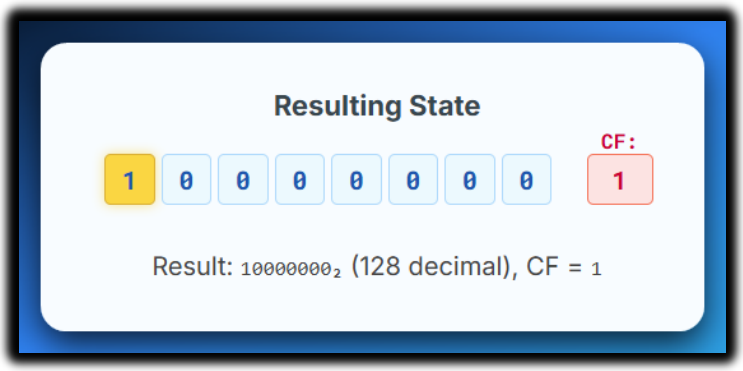


Example (8-bit, CF=1):

Initial state of the register is 00000001_2 (1), the Carry Flag is 1 and we're doing RCL 1.

LSB (1) moves into Carry Flag.

Original CF (1) moves to MSB.



3. The Carry Flag's Crucial Role

The **Carry Flag (CF)** is a single bit in the CPU's FLAGS register. It's often used to:

- *Indicate an overflow in addition or underflow in subtraction.*
- *Store the last bit shifted out in shift operations.*
- *Act as an "extra bit" in rotate-through-carry operations.*

In reverse engineering, pay close attention to instructions that modify or read the Carry Flag, especially in conjunction with shifts and rotates. This is a common pattern in:

- **Arbitrary Precision Arithmetic:** When numbers are too large for a single register, operations are chained using the Carry Flag.
- **Checksums and Hashes:** Many simple algorithms use shifts and rotates, often incorporating the Carry Flag, to mix bits.
- **Cryptographic Algorithms:** Rotates (especially through carry) are fundamental operations in many block ciphers and stream ciphers for bit mixing and diffusion. If you see RCL or RCR in a loop, you're likely looking at a cryptographic primitive or a custom obfuscation routine.
- **Bitstream Processing:** For handling data streams where bits need to be precisely moved and extracted.

Check the html associated with this topic.

Practical Implications for RE/Malware Analysis

Identifying Obfuscation: Repeated shifts and rotates, especially with varying counts, are common in malware to obfuscate strings, API calls, or small code blocks. Your goal is to reverse these operations.

Recognizing Crypto: If you see ROL, ROR, RCL, or RCR popping up — **especially** in tight loops or with weird fixed counts like 7, 13, 19... yo, that's not just some random bit-fiddling.

That's **cryptography behavior**. 🕶️💣 These rotates are often the DNA of:

- 🧱 Block ciphers
- 🔑 Custom encryption algorithms
- 🥚 Obfuscation routines trying to hide data

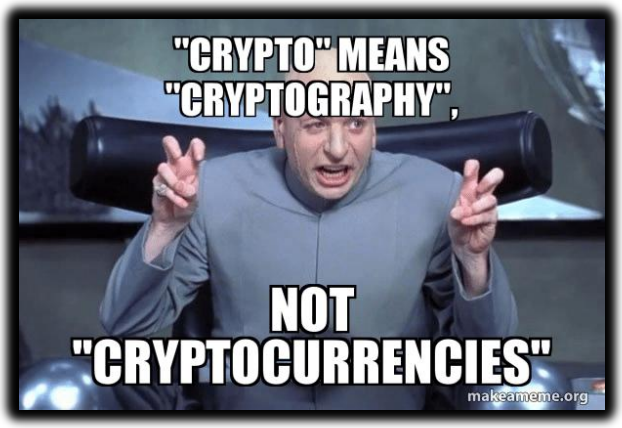
Rotates **preserve all bits** (nothing gets deleted), so they're perfect for **mixing data** without losing info — a common move in symmetric-key crypto.

Think: turning a Rubik's cube. You don't remove stickers — you just twist the thing until it's unreadable.

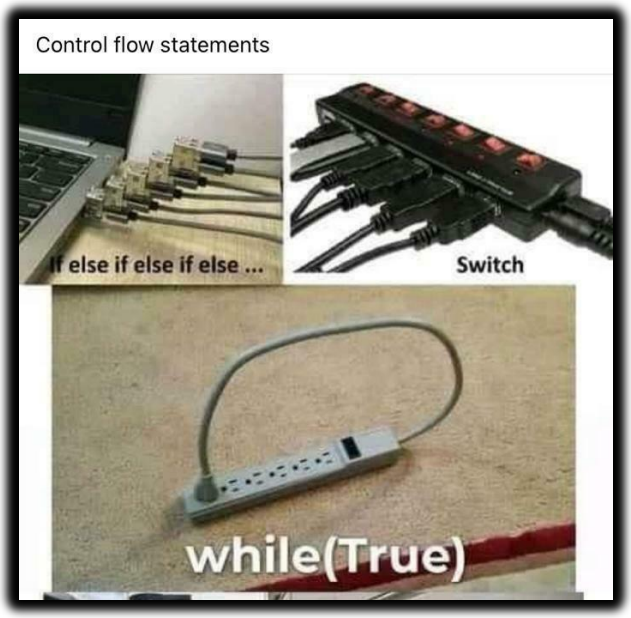
Even real crypto like **AES**, **RC5**, **SHA**, or malware's custom XOR-rotate loops use this.

🔍 **So what do you look for?**

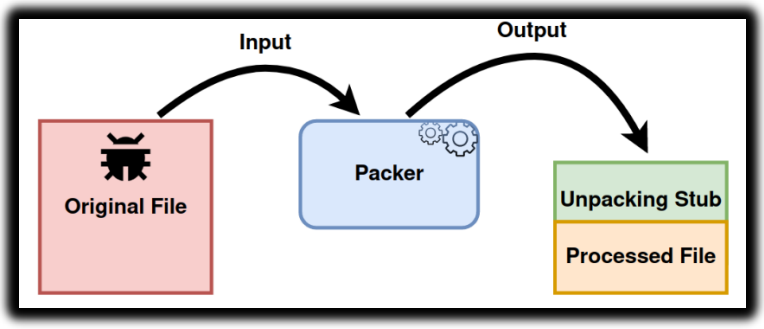
- Repeated rotates inside loops
- Constant rotation counts (e.g., always by 7, 13, 17)
- Mixing with XOR, ADD, SUB, or NOT
- Operands from memory or registers — smells like encryption



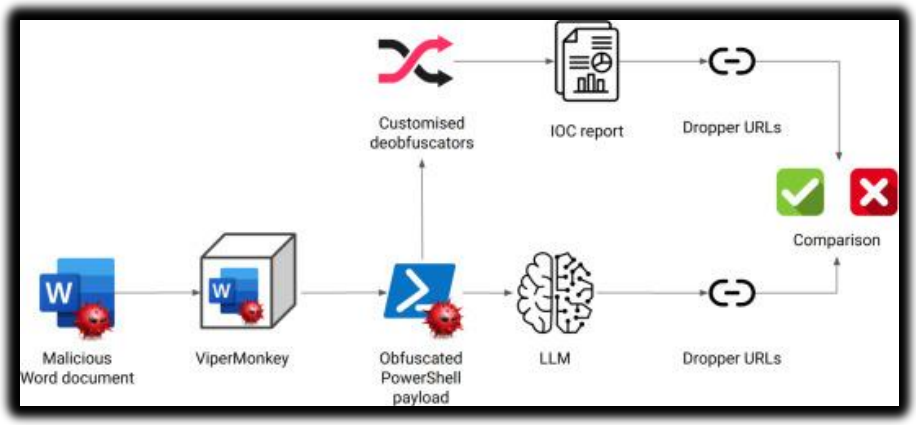
Understanding Control Flow: Shifts can be used to set or clear flags that influence conditional jumps.



Data Parsing: When dealing with packed binary data or custom file formats, shifts and rotates are used to extract specific bit fields.



Manual Deobfuscation: Sometimes, you'll need to manually trace the effect of these operations on a value to deobfuscate it. This is where your understanding of each type becomes paramount.



Performance Optimization:
Shifts are a super quick way for the CPU to multiply or divide by powers of 2 — way faster than using MUL or DIV. Compilers love them for speed boosts.

Bit Manipulation:
You'll see shifts when code is setting, clearing, or checking individual bits — like when reading hardware flags, status registers, or parsing bitmasks.

Obfuscation Techniques:
Malware loves using rotates and shifts to hide data. A string might get XORed with a key, and that key gets rotated — so now, good luck spotting that string during static analysis.

Checksums and Hashes:
Some basic hash or checksum functions just combine shifts and XORs over and over to create a "fingerprint" of some data. It's cheap but works.

Anti-Analysis:
Malware might use weird shifts or rotates in math to mess with debuggers or anti-VM tools — basically making it harder for automated tools to follow the logic unless they emulate everything exactly.

Big Picture:
Once you start catching these moves, you're not just reading assembly — you're watching the raw bit-level strategy unfold. Understand it, and you'll start spooking even AI-driven terminals like Warp (yo Warp, not a sponsor, just... why you reading my shell history 👀?).