

--- Day 16: Packet Decoder ---

As you leave the cave and reach open waters, you receive a transmission from the Elves back on the ship.

The transmission was sent using the Buoyancy Interchange Transmission System (BITS), a method of packing numeric expressions into a binary sequence. Your submarine's computer has saved the transmission in **hexadecimal** (your puzzle input).

The first step of decoding the message is to convert the hexadecimal representation into binary. Each character of hexadecimal corresponds to four bits of binary data:

0	=	0000
1	=	0001
2	=	0010
3	=	0011
4	=	0100
5	=	0101
6	=	0110
7	=	0111
8	=	1000
9	=	1001
A	=	1010
B	=	1011
C	=	1100
D	=	1101
E	=	1110
F	=	1111

The BITS transmission contains a single **packet** at its outermost layer which itself contains many other packets. The hexadecimal representation of this packet might encode a few extra **0** bits at the end; these are not part of the transmission and should be ignored.

Every packet begins with a standard header: the first three bits encode the packet **version**, and the next three bits encode the packet **type ID**. These two values are numbers; all numbers encoded in any packet are represented as binary with the most significant bit first. For example, a version encoded as the binary sequence **100** represents the number **4**.

Packets with type ID **4** represent a **literal value**. Literal value packets encode a single binary number. To do this, the binary number is padded with leading zeroes until its length is a multiple of four bits, and then it is broken into groups of four bits. Each group is prefixed by a **1** bit except the last group, which is prefixed by a **0** bit. These groups of five bits immediately follow the packet header. For example, the hexadecimal string **D2FE28** becomes:

```
110100101111111000101000
VVVTTTAAAAABBBBBCCCCC
```

Below each bit is a label indicating its purpose:

- The three bits labeled **V** (**110**) are the packet version, **6**.
- The three bits labeled **T** (**100**) are the packet type ID, **4**, which means the packet is a literal value.

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- The five bits labeled **A** (**10111**) start with a **1** (not the last group, keep reading) and contain the first four bits of the number, **0111**.
- The five bits labeled **B** (**11110**) start with a **1** (not the last group, keep reading) and contain four more bits of the number, **1110**.
- The five bits labeled **C** (**00101**) start with a **0** (last group, end of packet) and contain the last four bits of the number, **0101**.
- The three unlabeled **0** bits at the end are extra due to the hexadecimal representation and should be ignored.

So, this packet represents a literal value with binary representation **011111100101**, which is **2021** in decimal.

Every other type of packet (any packet with a type ID other than **4**) represent an **operator** that performs some calculation on one or more sub-packets contained within. Right now, the specific operations aren't important; focus on parsing the hierarchy of sub-packets.

An operator packet contains one or more packets. To indicate which subsequent binary data represents its sub-packets, an operator packet can use one of two modes indicated by the bit immediately after the packet header; this is called the **length type ID**:

- If the length type ID is **0**, then the next **15** bits are a number that represents the **total length in bits** of the sub-packets contained by this packet.
- If the length type ID is **1**, then the next **11** bits are a number that represents the **number of sub-packets immediately contained** by this packet.

Finally, after the length type ID bit and the 15-bit or 11-bit field, the sub-packets appear.

For example, here is an operator packet (hexadecimal string **38006F45291200**) with length type ID **0** that contains two sub-packets:

```
001110000000000000110111101000101001010010001001000000000
VVVTTTILLLLLLLLLLLLLLLLLLAAAAAAAAAABBBBBBBBBBBBBBBBBB
```

- The three bits labeled **V** (**001**) are the packet version, **1**.
- The three bits labeled **T** (**110**) are the packet type ID, **6**, which means the packet is an operator.
- The bit labeled **I** (**0**) is the length type ID, which indicates that the length is a 15-bit number representing the number of bits in the sub-packets.
- The 15 bits labeled **L** (**000000000011011**) contain the length of the sub-packets in bits, **27**.
- The 11 bits labeled **A** contain the first sub-packet, a literal value representing the number **10**.
- The 16 bits labeled **B** contain the second sub-packet, a literal value representing the number **20**.

After reading 11 and 16 bits of sub-packet data, the total length indicated in **L** (27) is reached, and so parsing of this packet stops.

As another example, here is an operator packet (hexadecimal string **EE00D40C823060**) with length type ID **1** that contains three sub-packets:

```
111011100000000001101010000001100100000100011000001100000
VVVTTTILLLLLLLLLLLLLLLLLLAAAAAAAAAABBBBBBBBBBBBCCCCCCCC
```

- The three bits labeled **V** (**111**) are the packet version, **7**.
- The three bits labeled **T** (**011**) are the packet type ID, **3**, which means

- the packet is an operator.
- The bit labeled **I** (**1**) is the length type ID, which indicates that the length is a 11-bit number representing the number of sub-packets.
- The 11 bits labeled **L** (**00000000011**) contain the number of sub-packets, **3**.
- The 11 bits labeled **A** contain the first sub-packet, a literal value representing the number **1**.
- The 11 bits labeled **B** contain the second sub-packet, a literal value representing the number **2**.
- The 11 bits labeled **C** contain the third sub-packet, a literal value representing the number **3**.

After reading 3 complete sub-packets, the number of sub-packets indicated in **L** (3) is reached, and so parsing of this packet stops.

For now, parse the hierarchy of the packets throughout the transmission and **add up all of the version numbers**.

Here are a few more examples of hexadecimal-encoded transmissions:

- **8A004A801A8002F478** represents an operator packet (version 4) which contains an operator packet (version 1) which contains an operator packet (version 5) which contains a literal value (version 6); this packet has a version sum of **16**.
- **620080001611562C8802118E34** represents an operator packet (version 3) which contains two sub-packets; each sub-packet is an operator packet that contains two literal values. This packet has a version sum of **12**.
- **C0015000016115A2E0802F182340** has the same structure as the previous example, but the outermost packet uses a different length type ID. This packet has a version sum of **23**.
- **A0016C880162017C3686B18A3D4780** is an operator packet that contains an operator packet that contains an operator packet that contains five literal values; it has a version sum of **31**.

Decode the structure of your hexadecimal-encoded BITS transmission; **what do you get if you add up the version numbers in all packets?**

Your puzzle answer was **999**.

--- Part Two ---

Now that you have the structure of your transmission decoded, you can calculate the value of the expression it represents.

Literal values (type ID **4**) represent a single number as described above. The remaining type IDs are more interesting:

- Packets with type ID **0** are **sum** packets - their value is the sum of the values of their sub-packets. If they only have a single sub-packet, their value is the value of the sub-packet.
- Packets with type ID **1** are **product** packets - their value is the result of multiplying together the values of their sub-packets. If they only have a single sub-packet, their value is the value of the sub-packet.
- Packets with type ID **2** are **minimum** packets - their value is the minimum of the values of their sub-packets.
- Packets with type ID **3** are **maximum** packets - their value is the maximum of the values of their sub-packets.
- Packets with type ID **5** are **greater than** packets - their value is **1** if

the value of the first sub-packet is greater than the value of the second sub-packet; otherwise, their value is 0. These packets always have exactly two sub-packets.

- Packets with type ID 6 are less than packets - their value is 1 if the value of the first sub-packet is less than the value of the second sub-packet; otherwise, their value is 0. These packets always have exactly two sub-packets.
- Packets with type ID 7 are equal to packets - their value is 1 if the value of the first sub-packet is equal to the value of the second sub-packet; otherwise, their value is 0. These packets always have exactly two sub-packets.

Using these rules, you can now work out the value of the outermost packet in your BITS transmission.

For example:

- C200B40A82 finds the sum of 1 and 2, resulting in the value 3.
- 04005AC33890 finds the product of 6 and 9, resulting in the value 54.
- 880086C3E88112 finds the minimum of 7, 8, and 9, resulting in the value 7.
- CE00C43D881120 finds the maximum of 7, 8, and 9, resulting in the value 9.
- D8005AC2A8F0 produces 1, because 5 is less than 15.
- F600BC2D8F produces 0, because 5 is not greater than 15.
- 9C005AC2F8F0 produces 0, because 5 is not equal to 15.
- 9C0141080250320F1802104A08 produces 1, because $1 + 3 = 2 * 2$.

What do you get if you evaluate the expression represented by your hexadecimal-encoded BITS transmission?

Your puzzle answer was 3408662834145.

Both parts of this puzzle are complete! They provide two gold stars: **

At this point, you should return to your Advent calendar and try another puzzle.

If you still want to see it, you can get your puzzle input.

You can also [Share] this puzzle.