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--- 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:

```
1101001011111111000101000
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.
- 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.

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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:

```
00111000000000000011011101000101001010010001001000000000
VVVTTTILLLLLLLLLLLLLLLAAAAAAAAAABBBBBBBBBBBBBBBBBB
```

- 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
VVVTTTILLLLLLLLLLLLLLLAAAAAAAAAABBBBBBBBBBBBCCCCCCCCCCC
```

- 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 `977`.

--- 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 `101501020883`.

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](#).

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