Syncrosoft MCFACT™
Secure Data Processing Technology

Re-trust Sixth Quarterly Meeting, March 11, 2008
Villach, Austria

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Who are we?

Syncrosoft
crypto & security solutions

- European company, established in 1991
  - Offices in Latvia and Germany
  - Software copy-protection
  - Protection of intellectual property
- Wulf Harder
  - Chief scientist and founder
- Atis Straujums
  - Lead of MCFACT development

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Challenge of Re-trust

"How to ensure that a trusted code base is running on an untrusted machine at all times and that the original code functionality has not been modified prior to or during run-time?"

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Capabilities of MCFACT

- Execute encrypted code on encrypted data without decrypting either of them
- Ensure code and data integrity
- Execute several independent functionalities concurrently and inseparably

All these features are useful in reaching the goals of the Re-trust project.

Agenda for today

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- What is MCFACT? (30 minutes)
  - Finite automata
  - Encoders
  - Automata composition
- Applying MCFACT (10 minutes)
  - Example in C++
  - MCFACT design variants
  - Speed and size of protected code
- AES white-box implementation (10 minutes)
  - Resistance against attack by Olivier Billet et al.
  - Techniques usable in Re-trust
- Discussion (5 minutes)

What is MCFACT?

What is MCFACT?

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MCFACT [em see fakt'] **stands for:**

Multi-Channel Finite Automata Code Transformation

MCFACT is used to:

- Execute encrypted code on encrypted data without decrypting either of them
- Ensure code and data integrity
- Execute several independent functionalities concurrently and inseparably

What is MCFACT?

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MCFACT is comprised of the following concepts:

- Multi-channel finite automata
  - Operation automata
  - Encoder automata
- Composition
  - Sequential
  - Parallel
- Colours

What is MCFACT?

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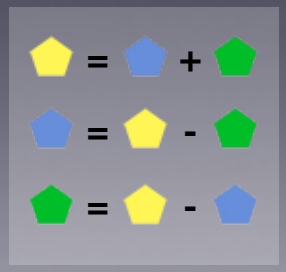
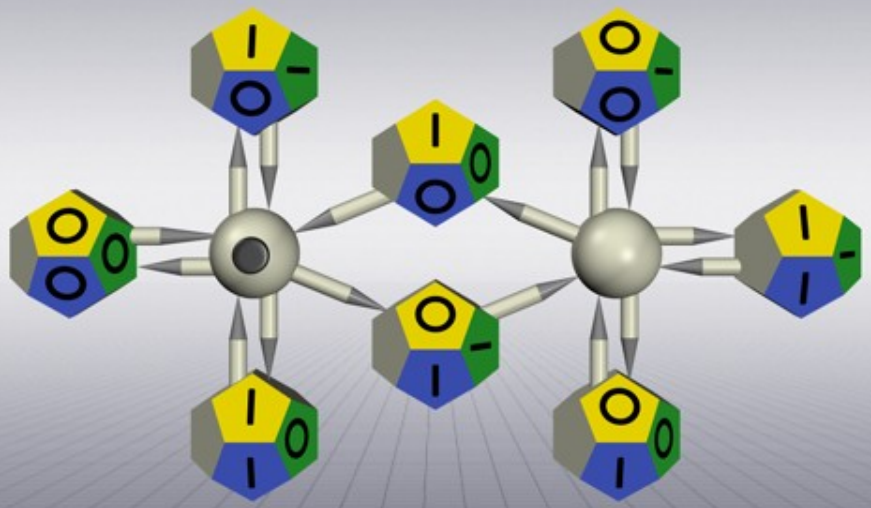
Demonstration of execution of a multi-channel finite automaton

- Two operations are executed in parallel
- Two channels are read from, two are written to

Go to demonstration





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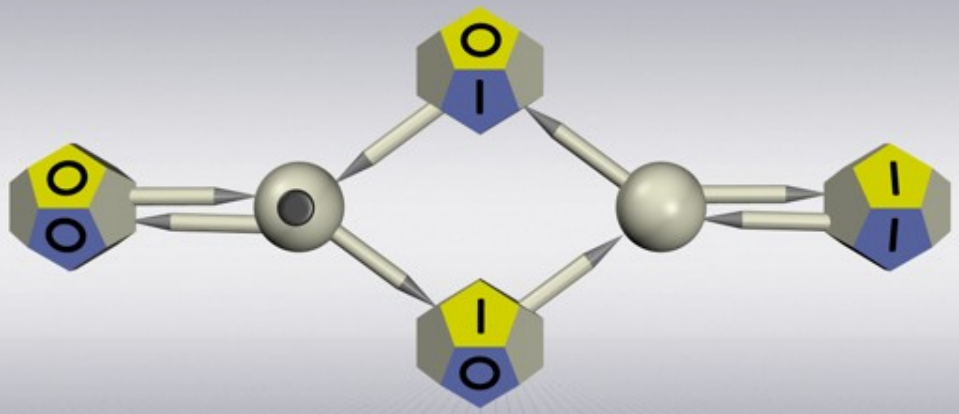

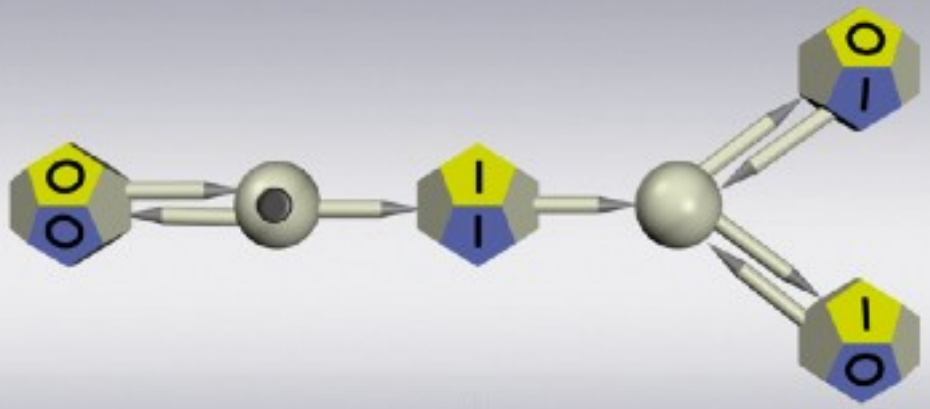

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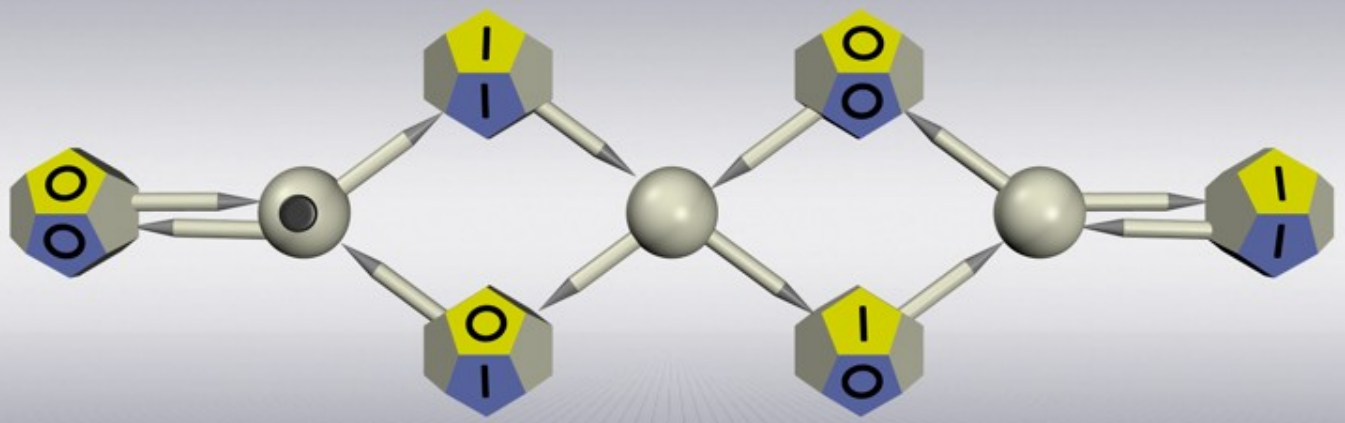

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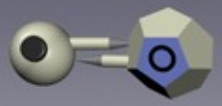

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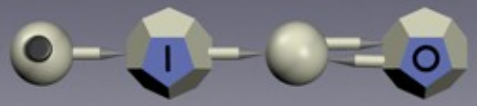

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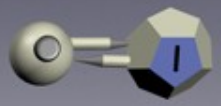

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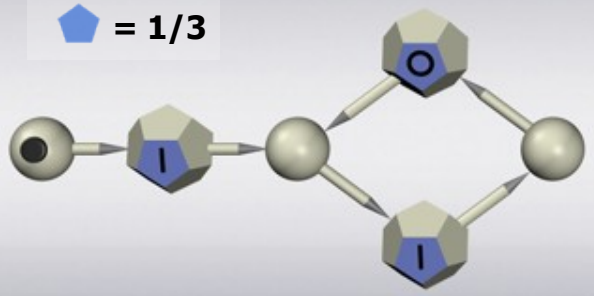

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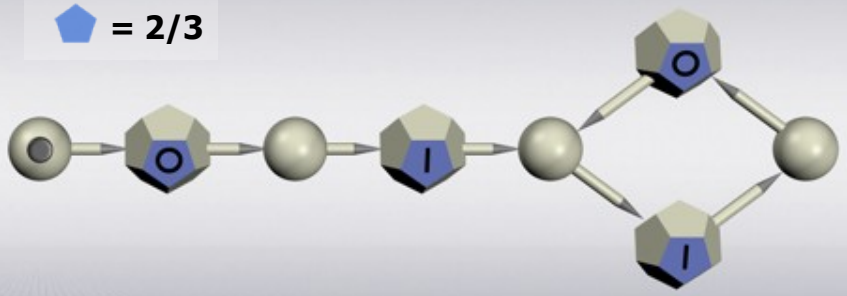

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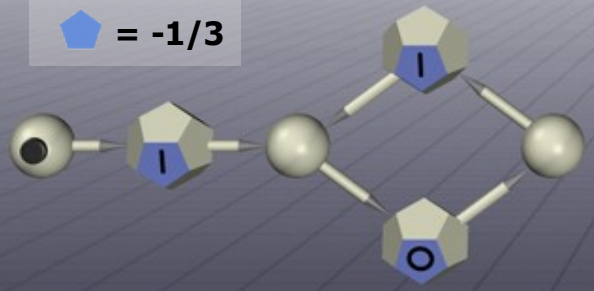

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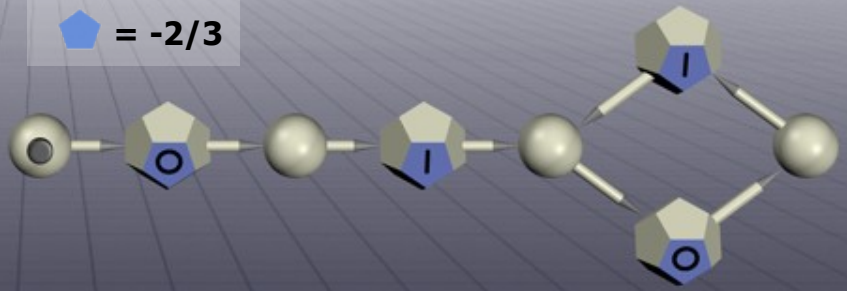

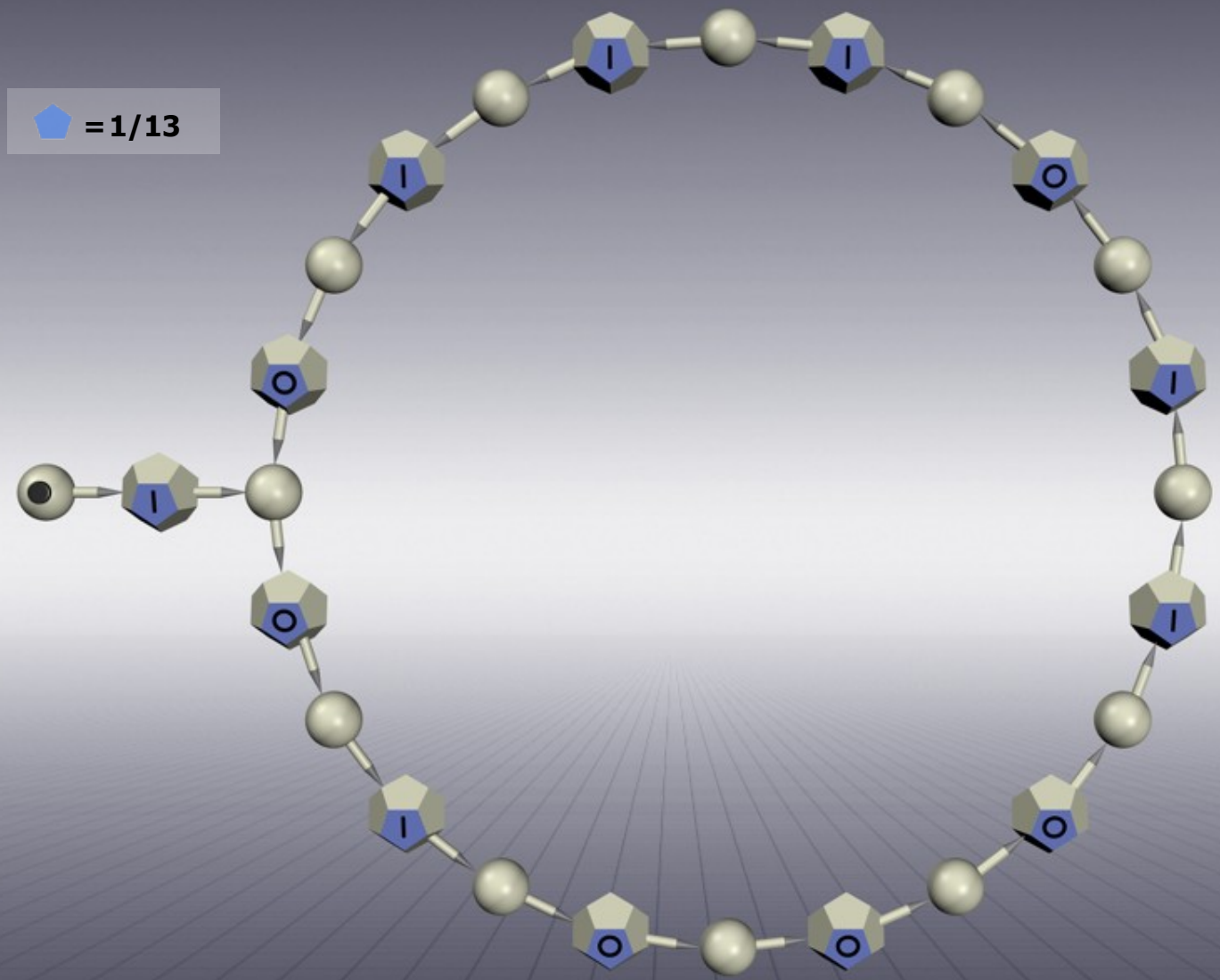
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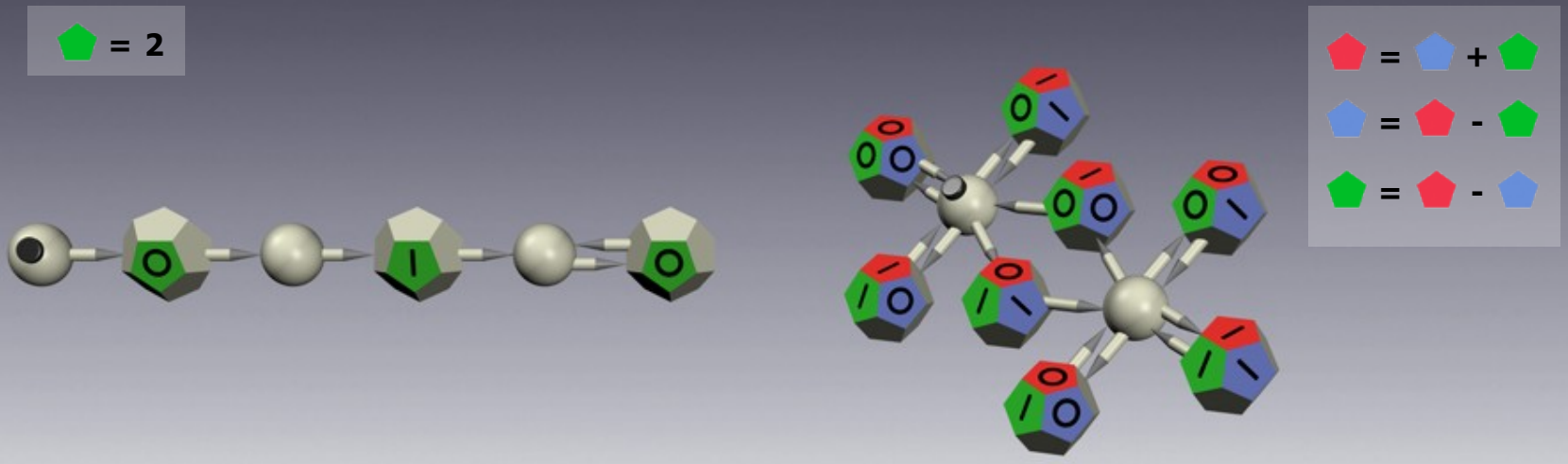
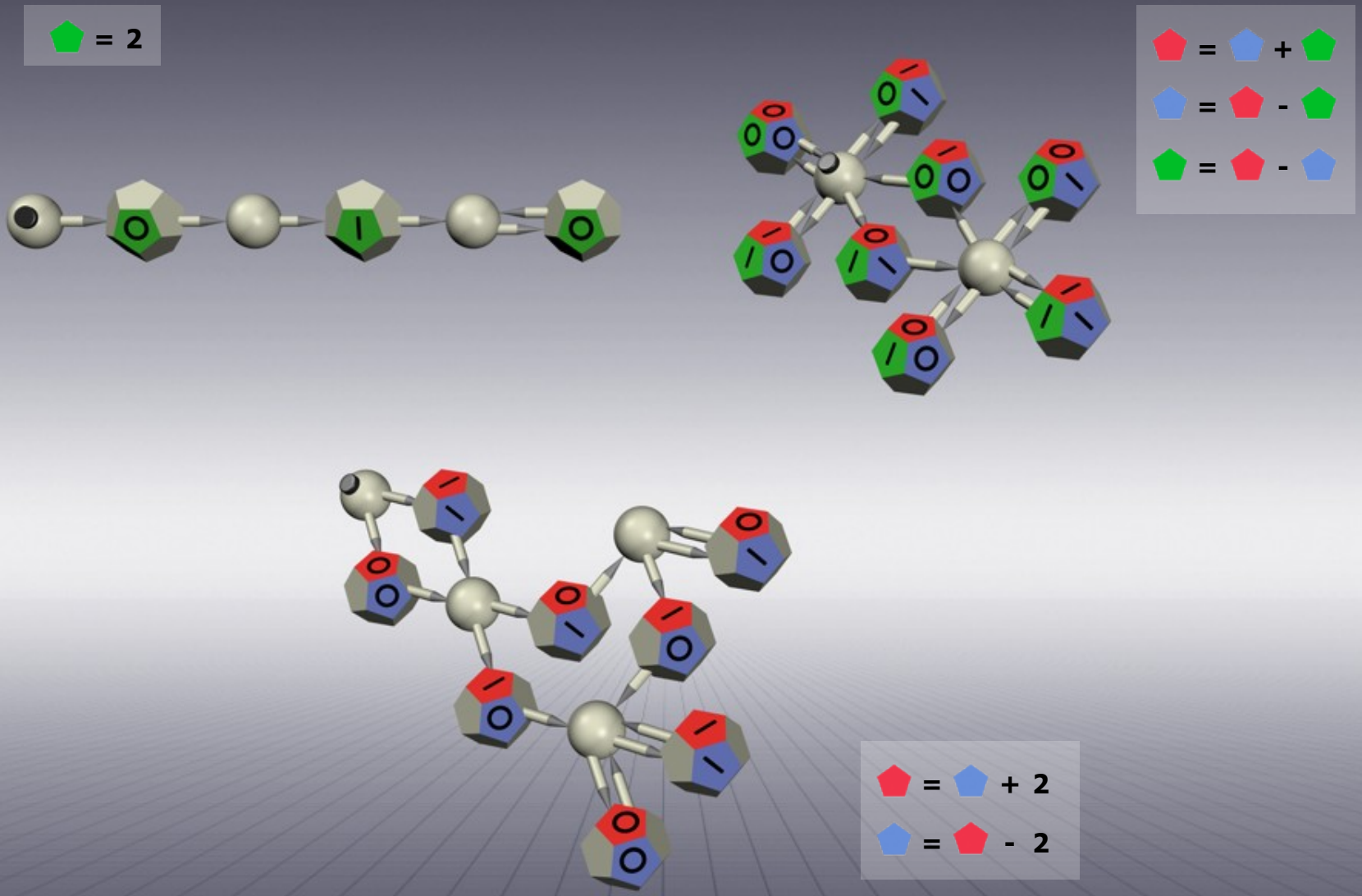


Composition example movie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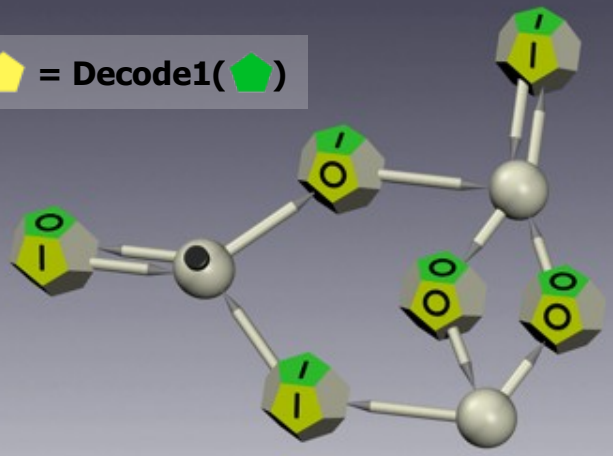
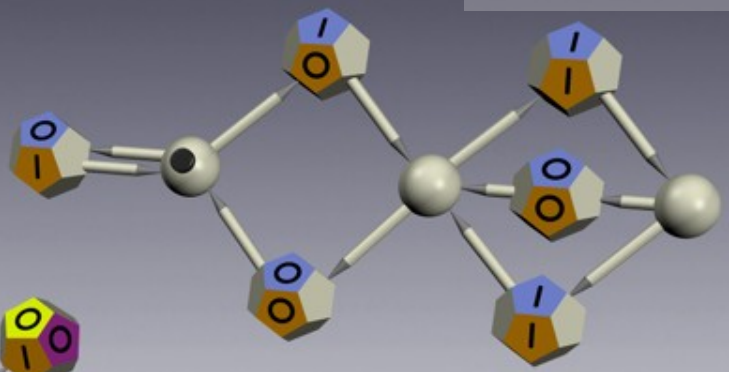
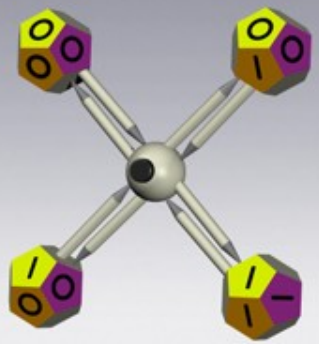
= +
= -
= -
= + 2
= - 2

= Decode1( )



= Decode2( )





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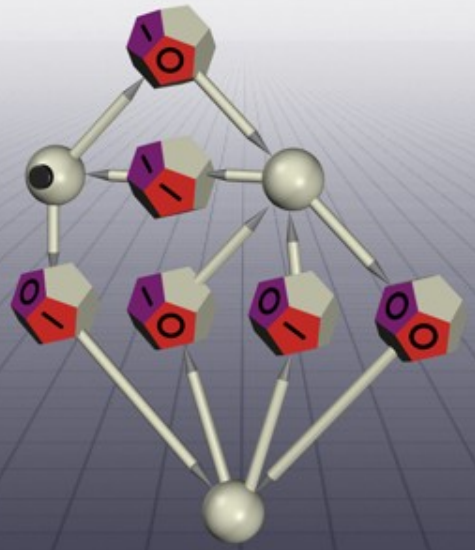
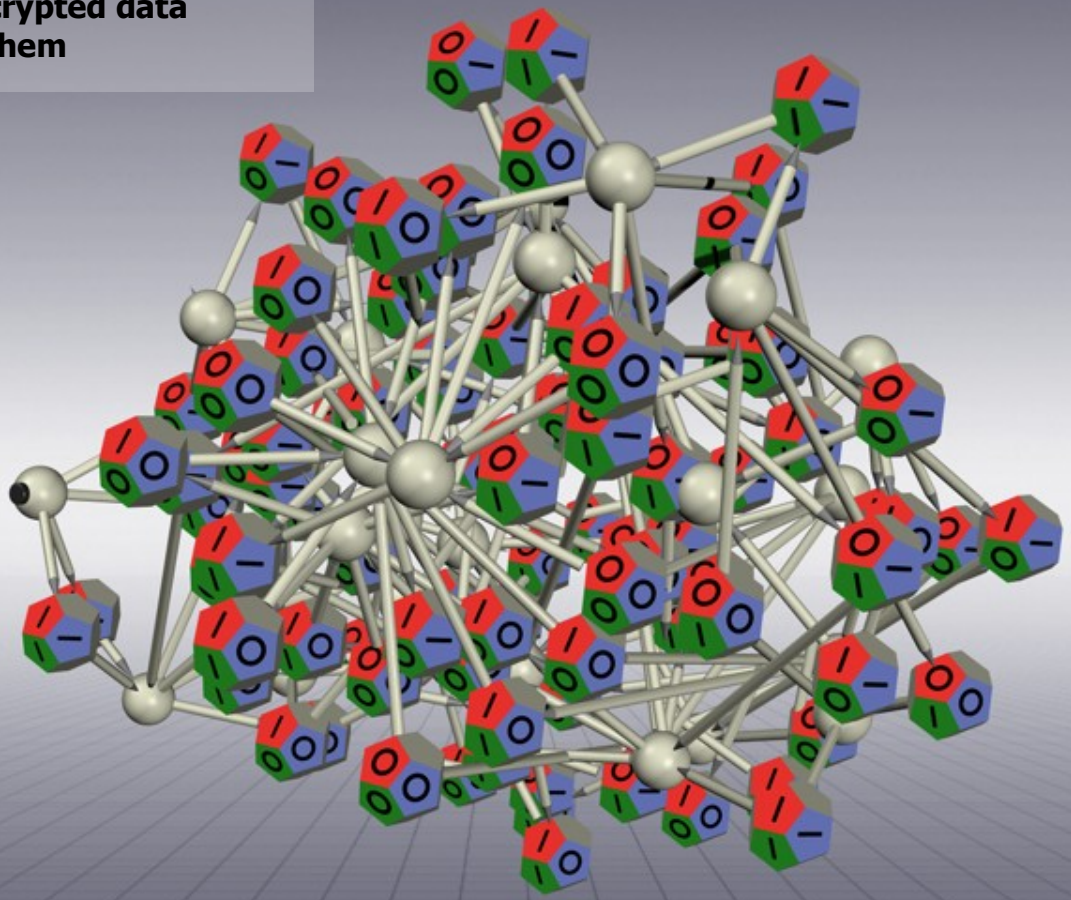


= Encode( )

= Encode(Decode1( ) & Decode2( ))

Composed automaton that performs bitwise AND on encrypted data without revealing them



What is MCFACT?

Known decomposition algorithms

- Have time complexity between $O(N^2)$ and $O(N^3)$
- Decomposition is not unique
- N is the number of states
- In MCFACT, states are represented as a bit vector
- Security is adjusted by choosing the number of state bits

What is MCFACT?

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"Just as it is hard to factor the product of two large primes, it is also hard to factor the composition of two finite automata."

Bruce Schneier, Applied Cryptography, John Wiley & Sons, 1996.

Comment by Syncrosoft:

- The complexity class of factoring is unknown
- The complexity class of decomposition with regards to the number of states (N) is P
- The complexity class of decomposition with regards to the size of the bit vectors that represent states is unknown

What is MCFACT?

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MCFACT uses similar principles as FAPKC

- Renji Tao, Shihua Chen, "Finite automata public key cryptosystem and digital signature", Computer Acta, Vol. 8, No. 6, 1985, pp. 401-409. (in Chinese)
- Public key cryptosystem based on finite automata
- Based on the decomposition problem

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FAPKC – broken but without decomposition

- Feng Bao, Yoshihide Igarashi, "Break Finite Automata Public Key Cryptosystem", ICALP 1995, pp. 147-158.
- Demonstration of how to break FAPKC by inverting the public key automaton
- No decomposition is used
- New version of FAPKC was proposed by original authors in 1995

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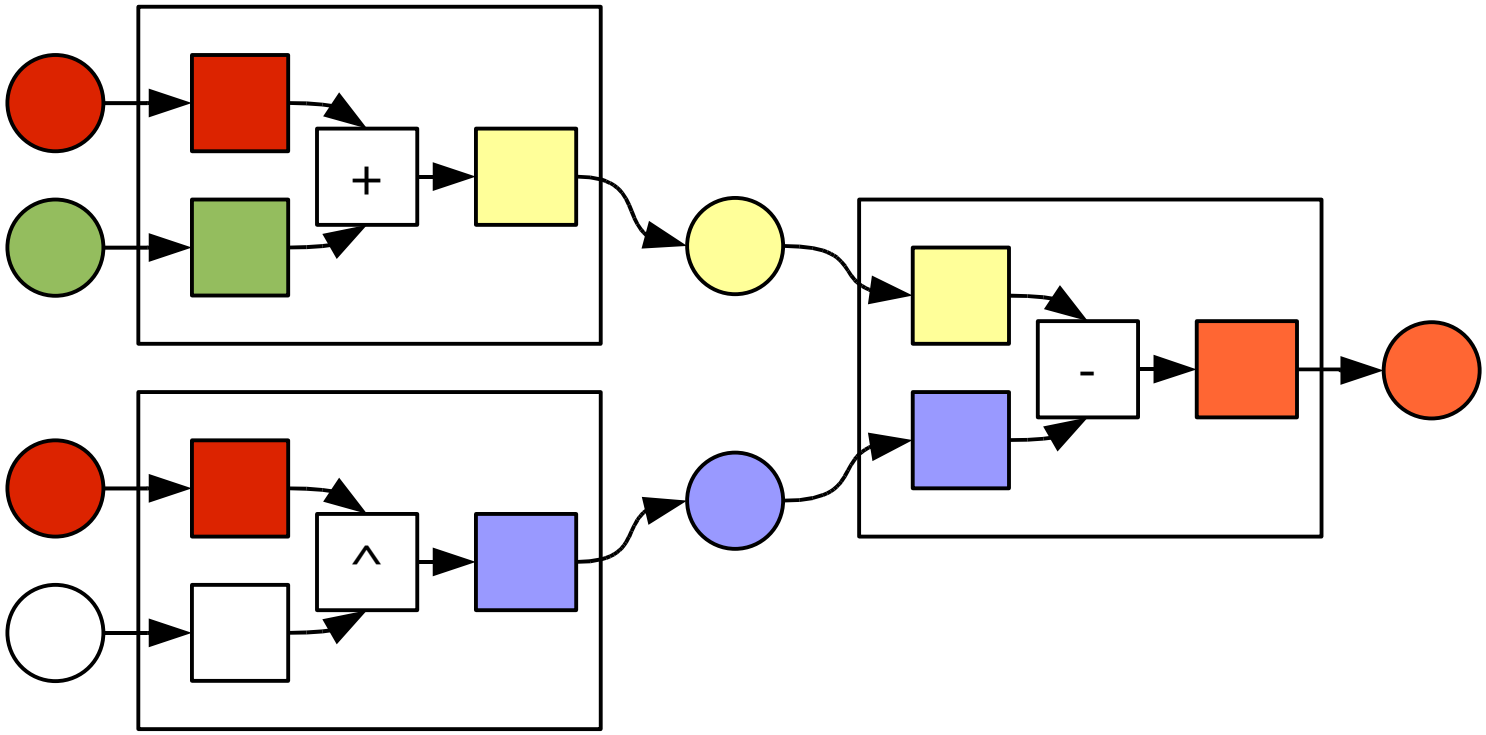
Colours – MCFACT way to ensure code integrity



Applying MCFACT

Applying MCFACT

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Current tools implement MCFACT as a source-code level protection

- Supported languages
  - C/C++
- Integration in development environments
  - Microsoft Visual Studio
- Protected code works on popular platforms/compilers
  - Microsoft Visual C/C++ (6, 7, 8)
  - GCC (3, 4)
  - Microsoft Windows
  - MacOS (PowerPC and Intel)
  - Linux (eLicenser support pending)

Applying MCFACT

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Example

- Easy to use system
- Protected code and data
- Code integrity
- Virtual Processor

Applying MCFACT

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```
//MCFACT_PROTECTED
unsigned int findInverse(unsigned int n)
{
    unsigned int test = 1;
    unsigned int result = 0;
    unsigned int mask = 1;
    while (test != 0)
    {
        if (mask & test)
        {
            result |= mask;
            //MCFACT_AUTHORIZED
            test -= n;
        }
        mask <<= 1;
        n <<= 1;
    }
    return result;
}
```

Applying MCFACT

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```
unsigned int findInverse(unsigned int n)
{
  ...
  class _calculations_cpp_test_0 test=((_init0_0::_init0)());
  class _calculations_cpp_result_0 result=((_init1_0::_init1)());
  class _calculations_cpp_mask_0 mask=((_init2_0::_init2)());
  _cycle1:{
    signed char tmp8;
    ((tmp8)=((IsNotEqual)((test), (_calculations_cpp_c_0_0))));
    if ((tmp8)) {
      {
        unsigned int tmp7;
        ((And)((mask), (test), (tmp7)));
        if ((tmp7)) {
          ((Or)((result), (mask), (result)));
          ((Sub)((test), (n), (test)));
        }
        ((ShiftLeftOne)((mask), (mask)));
        ((n)<<=(1U));
      }
      goto _cycle1;
    }
  }
  {
    unsigned int tmp9;
    ((Copy)((result), (tmp9)));
    return(tmp9);
  }
}
```

```
//MCFACT_PROTECTED
unsigned int findInverse(unsigned int n)
{
    unsigned int test = 1;
    unsigned int result = 0;
    unsigned int mask = 1;
    while (test != 0)
    {
        if (mask & test)
        {
            result |= mask;
            //MCFACT_AUTHORIZED
            test -= n;
        }
        mask <<= 1;
        n <<= 1;
    }
    return result;
}
```

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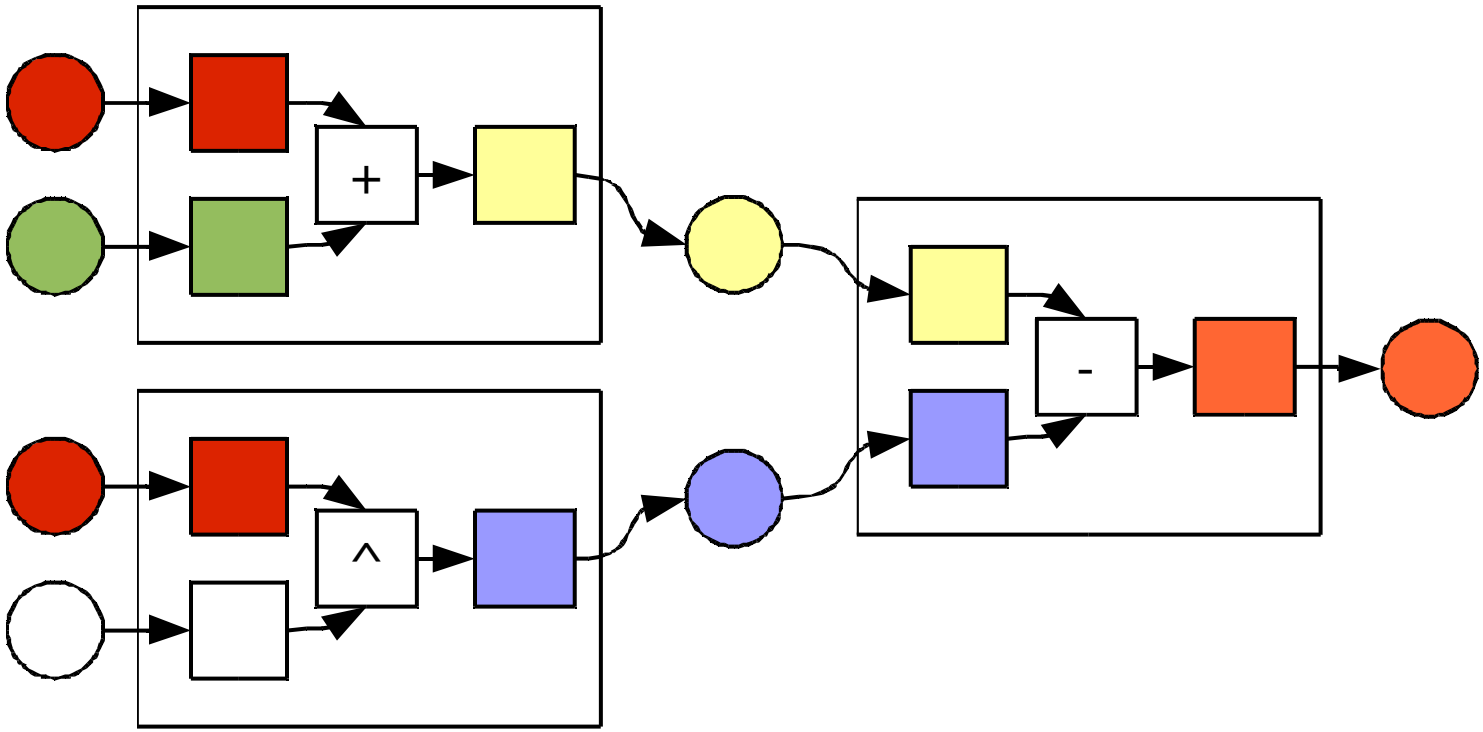
Operations work on certain colours



Applying MCFACT

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```
void Or(
    const _calculations_cpp_result_0& arg0,
    const _calculations_cpp_mask_0& arg1,
    _calculations_cpp_result_0& arg2)
{
  static const short opCodeLarge[40] = {
    61, 14, 10, 3, 45, 22, 10, 5, 39, 34, 32, 53, 53, 54, 54, 53, 27, 1, 34, 32,
    32, 34, 27, 43, 34, 43, 54, 53, 54, 1, 39, 39, 1, 32, 43, 53, 53, 39, 39, 53
  };
  static const short opCodeSmall[40] = {
    16, 112, 96, 48, 16, 32, 0, 112, 32, 64, 48, 16, 80, 80, 16, 112, 48, 112, 32, 48,
    112, 112, 0, 112, 80, 96, 32, 64, 0, 0, 0, 112, 112, 32, 96, 16, 48, 96, 112, 64
  };
  MainFunction(
    arg0.value_skJ35dF4i2,
    arg1.value_skJ35dF4i2,
    arg2.value_skJ35dF4i2,
    opCodeSmall, opCodeLarge,
    0, 40, 40, 40
  );
}
```

Applying MCFACT

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```
void MainFunction (
    const unsigned char * var1, const unsigned char * var2, unsigned char * resultVar,
    const short * opC1, const short * opC2, int stwb, int varLength1, int varLength2,
    int varLength3)
{
  unsigned int currentState, currentState2, nextState, nextState2, res;
  int varLength = varLength1, i;
  static const int firstSteps[512] = {287810,1859014,1736134,1723842,...,1974800};

  currentState = currentState2 = 0;
  if (varLength2 < varLength) varLength = varLength2;
  if (varLength3 < varLength) varLength = varLength3;
  for (i = 0; i < varLength; i++) {
    nextState = first7table0Func()[((var1[i] & 3) << 2) | ((var2[i] & 3) << 0)
      | (opC1[i]) | ((currentState & 528482304) >> 16)];
    nextState ^= first7table1Func()[(currentState >> 16) & 127];
    nextState ^= first7table2Func()[(currentState >> 8) & 255];
    nextState ^= first7table3Func()[(currentState >> 0) & 255];
    currentState = nextState;
    res = (nextState & 3758096384u);
    nextState2 = second7table0Func()[(res >> 23) | (opC2[i]) | ((currentState2
      & 1966080) >> 8)];
    nextState2 ^= second7table1Func()[(currentState2 >> 12) & 31];
    nextState2 ^= second7table2Func()[(currentState2 >> 6) & 63];
    nextState2 ^= second7table3Func()[(currentState2 >> 0) & 63];
    resultVar[(i)?(i - stwb):0] = (nextState2 >> 21)& 3;
    currentState2 = nextState2;
    ...
  }
}
```

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Speed and size

- Speed and size depend on the security level
- For a given security, speed can be increased at the expense of size

Applying MCFACT

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Examples of the functionality that is protected with MCFACT:

- Memory allocation
- Custom GUI controls
- Pointer arithmetic
- File encryption
- Hashing algorithms

Applying MCFACT

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MCFACT is used by:

- Microsoft
- Yamaha
- Steinberg
- Vienna Symphonic Library
- Korg
- Eleco
- many more...

AES white-box implementation

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Attack by Olivier Billet et al.

- Chow, S., Eisen, P.A., Johnson, H., van Oorschot, P.C.,

White-Box Cryptography and an AES Implementation, In Nyberg, K., Heys, H.M., eds.: Selected Areas in Cryptography – SAC 2002. Volume 2595 of Lecture Notes in Computer Science, Springer Verlag (2003) 250–270. http://citeseer.ist.psu.edu/736207.html

- Olivier Billet, Henri Gilbert, Charaf Ech-Chatbi,

Cryptanalysis of a White Box AES Implementation, H. Handschuh and A. Hasan (Eds.): SAC 2004, LNCS 3357, pp. 227–240, Springer-Verlag Berlin Heidelberg 2005. http://bo.blackowl.org/research/paper/wbaes-cryptanalysis

AES white-box implementation

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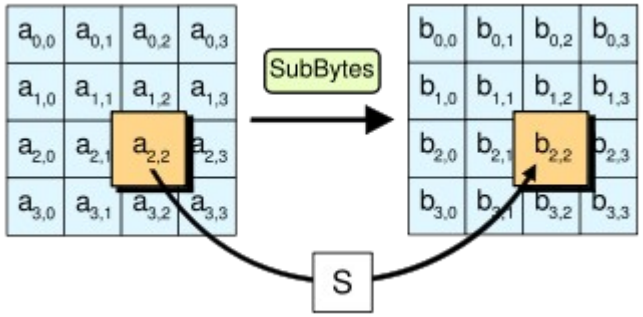
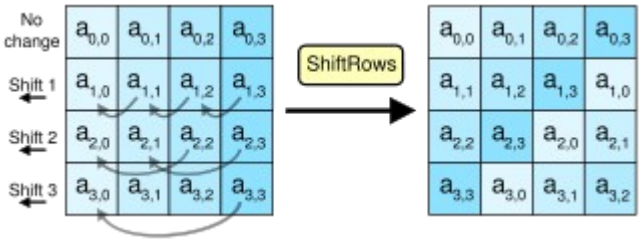
AES algorithm

1)



2)



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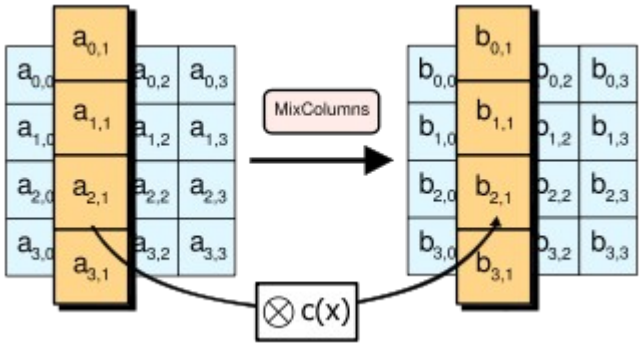

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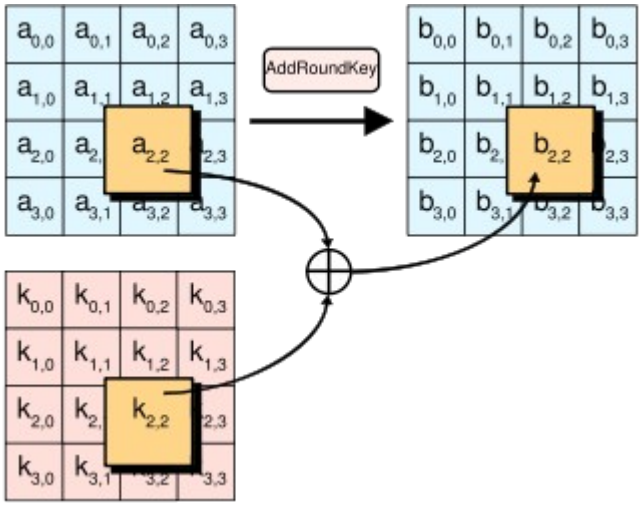

Illustrations: http://en.wikipedia.org/wiki/Advanced_Encryption_Standard

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Attack by Olivier Billet et al.

The main condition for the attack to be successful is:

- It must be possible to compare if a certain byte has the same value for two AES runs that use different inputs.

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Solution using MCFACT

- Encrypted data throughout the algorithm
- Random component in every variable
- Code integrity based on colours
- Data integrity – hash of input that is checked parallel to useful operations

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Random component in every variable

- Each MCFACT-protected variable can contain several values (meaningful value, random, hash)
- Operations can change each value independently yet inseparably
- Random component is changed to achieve maximum data diversity (dependency on the history of operations)

AES white-box implementation

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Code integrity based on colours

- All loops are unrolled
- Each byte has own colour
- Only matching colours produce correct results
- SubBytes and MixColumns are implemented using calculations instead of table look-ups

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Data integrity due to hashing

- Hash of all inputs of algorithm is calculated
- Hash is stored inseparably together with every input
- Each operation checks if hashes of both arguments match
- If they don't, the calculation produces errors

Summary

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MCFACT:

- Executes encrypted code on encrypted data without decrypting either of them
- Ensures code and data integrity
- Executes several independent functionalities concurrently and inseparably

- Is used to solve challenges similar to those of the Re-trust project
- Is complementary to other trust-ensuring techniques (e.g. TrustedFlow, obfuscation, etc.)

Questions, please!

Supplemental slides:

- Finite automata or polynomials?
- MCFACT vs. obfuscation
- MCFACT approach to control flow integrity
- Attacks on MCFACT
- Other Syncrosoft projects

Thank you!

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Automata or polynomials?

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XOR of numbers 0..10 using polynomials:

$$\begin{aligned}\mathrm{XOR}(x,y) = {} & x+y+2xy+8x^3y+3x^7y+9x^9y+10x^{10}y+6x^2y^2+6x^3y^2+5x^4y^2+x^5y^2+\\ & 3x^6y^2+3x^7y^2+2x^8y^2+6x^9y^2+x^{10}y^2+8xy^3+6x^2y^3+7x^3y^3+5x^4y^3+\\ & 4x^5y^3+3x^6y^3+7x^7y^3+2x^8y^3+9x^9y^3+6x^{10}y^3+5x^2y^4+5x^3y^4+\\ & 6x^4y^4+10x^5y^4+8x^6y^4+8x^7y^4+9x^8y^4+5x^9y^4+10x^{10}y^4+x^2y^5+4x^3y^5+\\ & 10x^4y^5+7x^5y^5+6x^6y^5+4x^7y^5+4x^8y^5+2x^9y^5+x^{10}y^5+3x^2y^6+3x^3y^6+8x^4y^6+\\ & 6x^5y^6+7x^6y^6+7x^7y^6+x^8y^6+3x^9y^6+6x^{10}y^6+3xy^7+3x^2y^7+7x^3y^7+\\ & 8x^4y^7+4x^5y^7+7x^6y^7+7x^7y^7+x^8y^7+9x^9y^7+3x^{10}y^7+2x^2y^8+2x^3y^8+\\ & 9x^4y^8+4x^5y^8+x^6y^8+x^7y^8+8x^8y^8+2x^9y^8+4x^{10}y^8+9xy^9+6x^2y^9+\\ & 9x^3y^9+5x^4y^9+2x^5y^9+3x^6y^9+9x^7y^9+2x^8y^9+10x^9y^9+6x^{10}y^9+\\ & 10xy^{10}+x^2y^{10}+6x^3y^{10}+10x^4y^{10}+x^5y^{10}+6x^6y^{10}+3x^7y^{10}+\\ & 4x^8y^{10}+6x^9y^{10}+7x^{10}y^{10} \pmod{11}\end{aligned}$$

Automata or polynomials?

Syncrosoft
crypto & security solutions

Difficulty of some operations in each domain

		MCFACT	
		Easy	**Hard**
Polynomials	**Easy**	Add, Sub, Neg, bitwise Not	Mul
	Hard	bitwise Xor, And, Or	bitwise rotation

← Back to questions

MCFACT vs obfuscation

encrypt

1. To put into code or cipher.

2. *Computer Science* To alter (a file, for example) using a secret code so as to be unintelligible to unauthorized parties.

obfuscate

1. To make so confused or opaque as to be difficult to perceive or understand: "A great effort was made . . . to obscure or obfuscate the truth" Robert Conquest.

2. To render indistinct or dim; darken: The fog obfuscated the shore.

The American Heritage® Dictionary of the English Language, Fourth Edition.
Copyright© 2004, 2000 by Houghton Mifflin Company.

MCFACT vs obfuscation

Syncrosoft
crypto & security solutions

Security of MCFACT:

- Data are encrypted and never appear plain
- Code is encrypted and never appears plain
- Stream encryption using finite automata
- Decryption, processing and encryption are composed into single finite automaton
- Decomposition is a hard problem for large automata

← Back to questions

Control flow integrity

Syncrosoft
crypto & security solutions

MCFACT relies on repeated verification to ensure control flow:

- Condition is checked and branch is taken
- In each branch condition is checked again
  - Parallel composition is used to prevent tampering
- If repeated condition check fails, data get corrupted

← Back to questions

Attacks on MCFACT?

Syncrosoft
crypto & security solutions

MCFACT has never been broken!

- The last successful attack on the link between MCFACT and eLicenser has been published in June, 2005

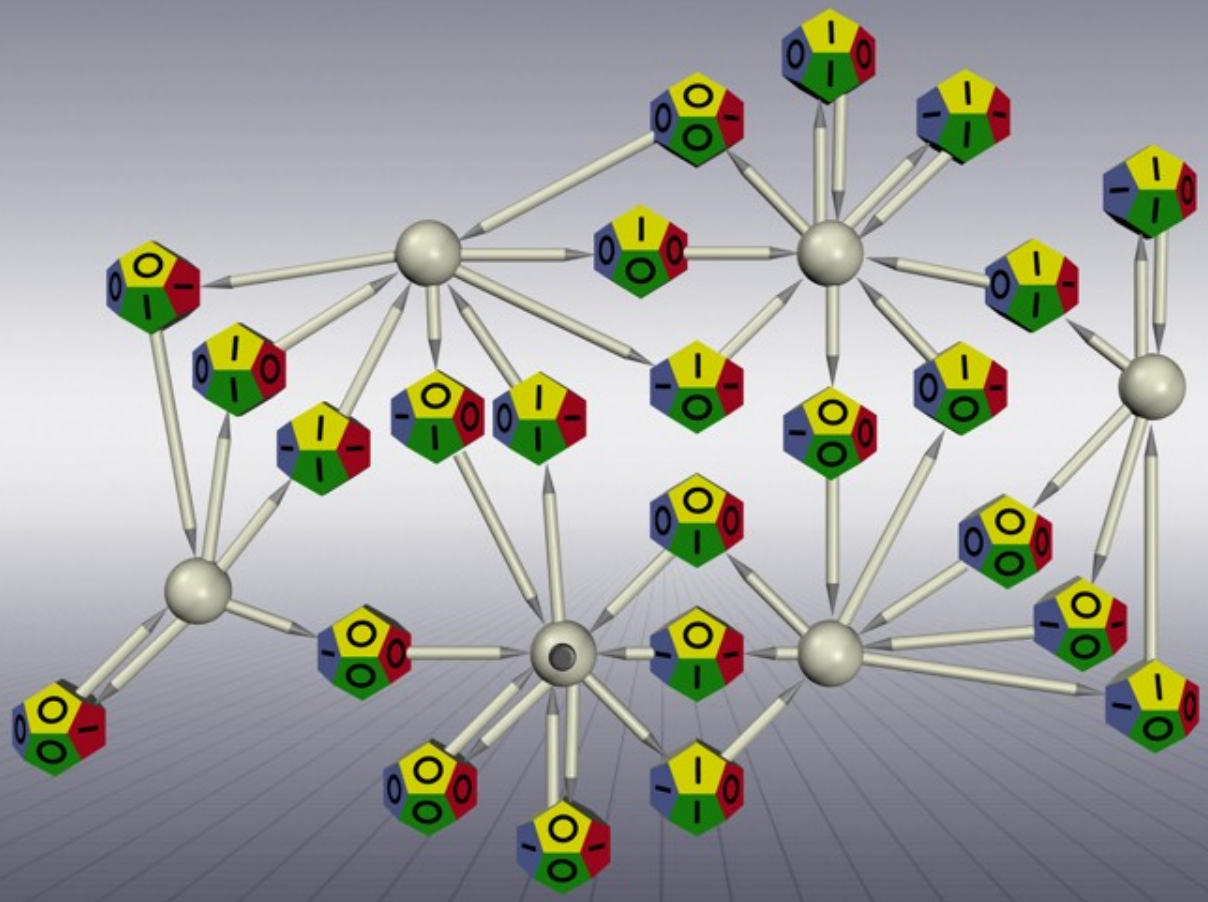
← Back to questions

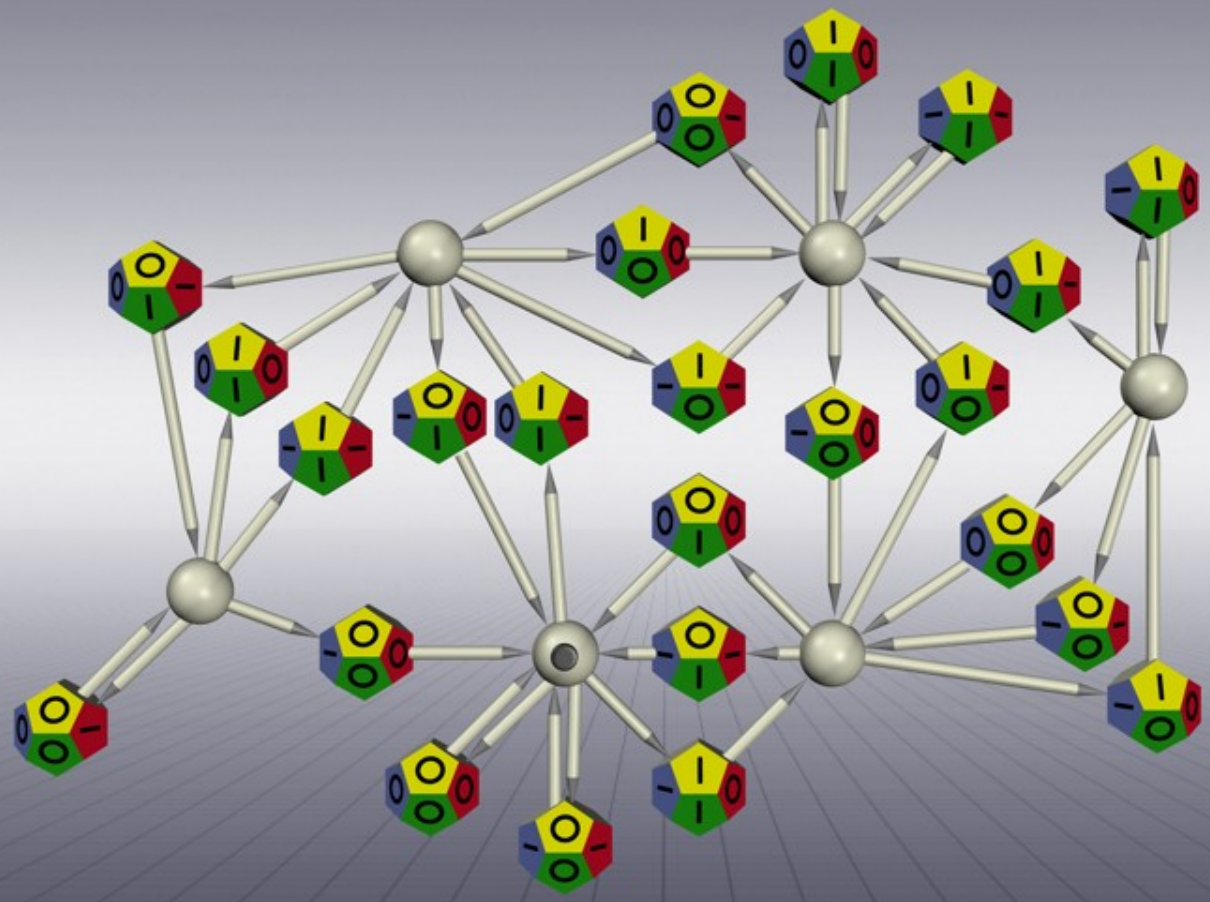
What else is Syncrosoft doing?

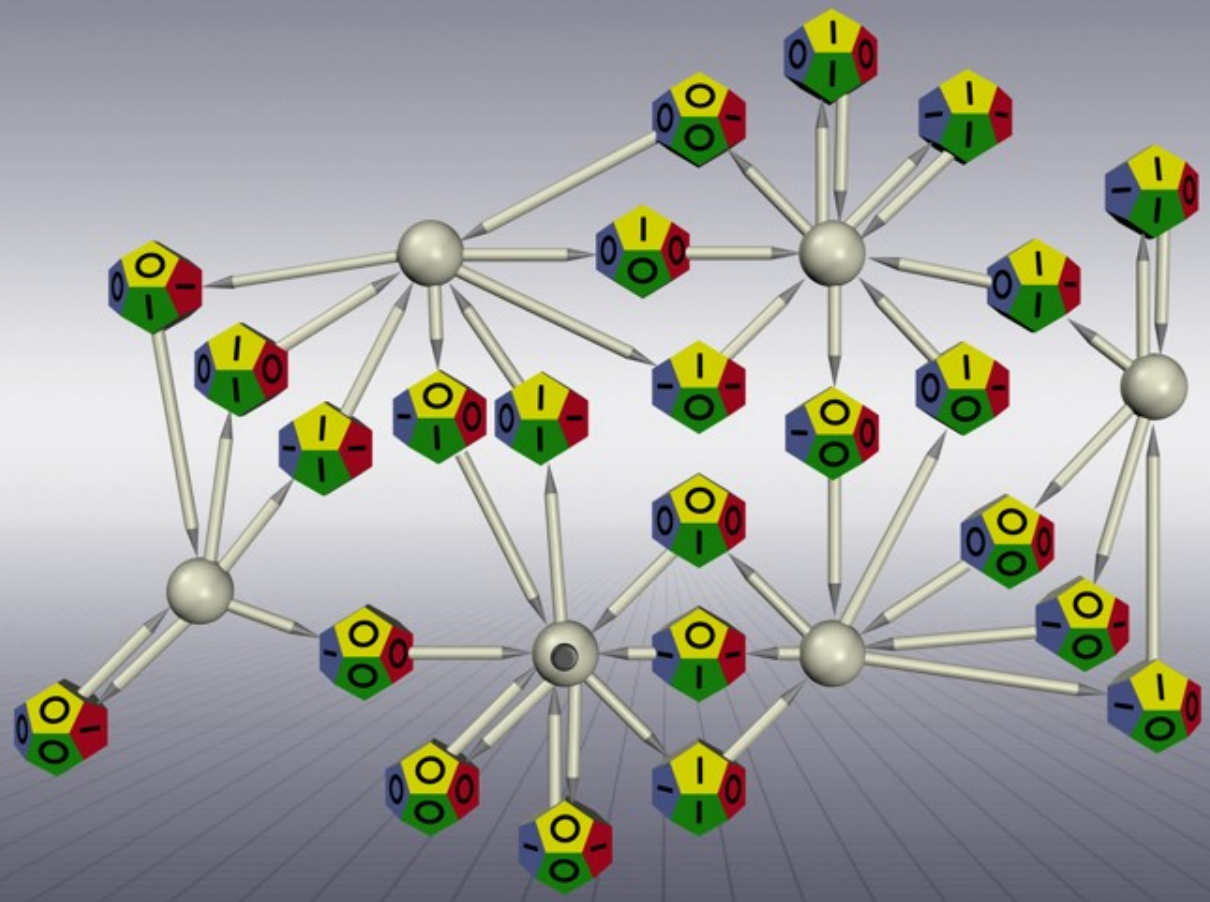
Main projects Syncrosoft is working on:

- Cryptography toolbox (ECC, AES, DES, TDES, SHA-1, SHA-256, RSA coming soon)
- Alternative protected domains
- 1:N symmetric encryption
- Analyser – cryptanalysis tool
- Software copy protection and licensing system, using dedicated hardware – eLicenser
- Digital content protection

← Back to questions



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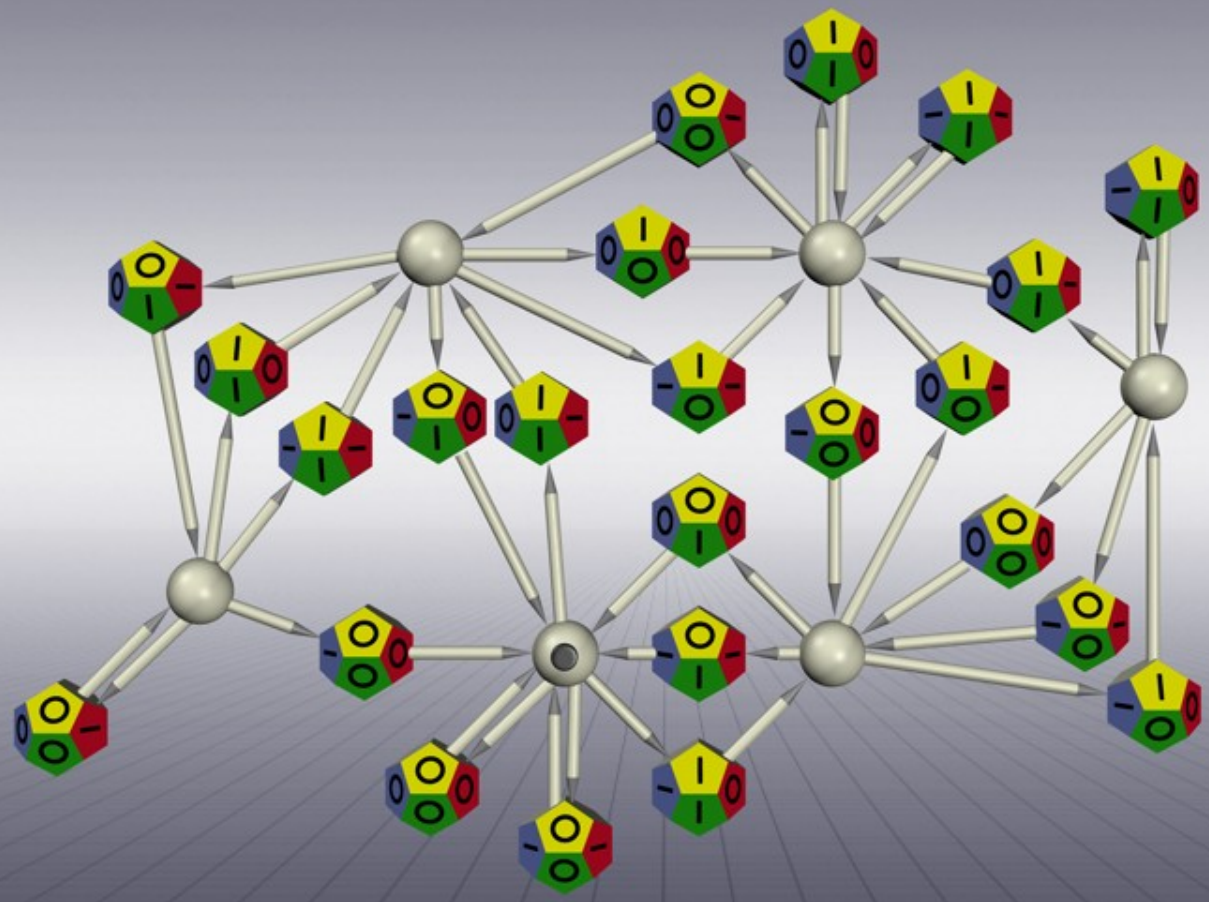

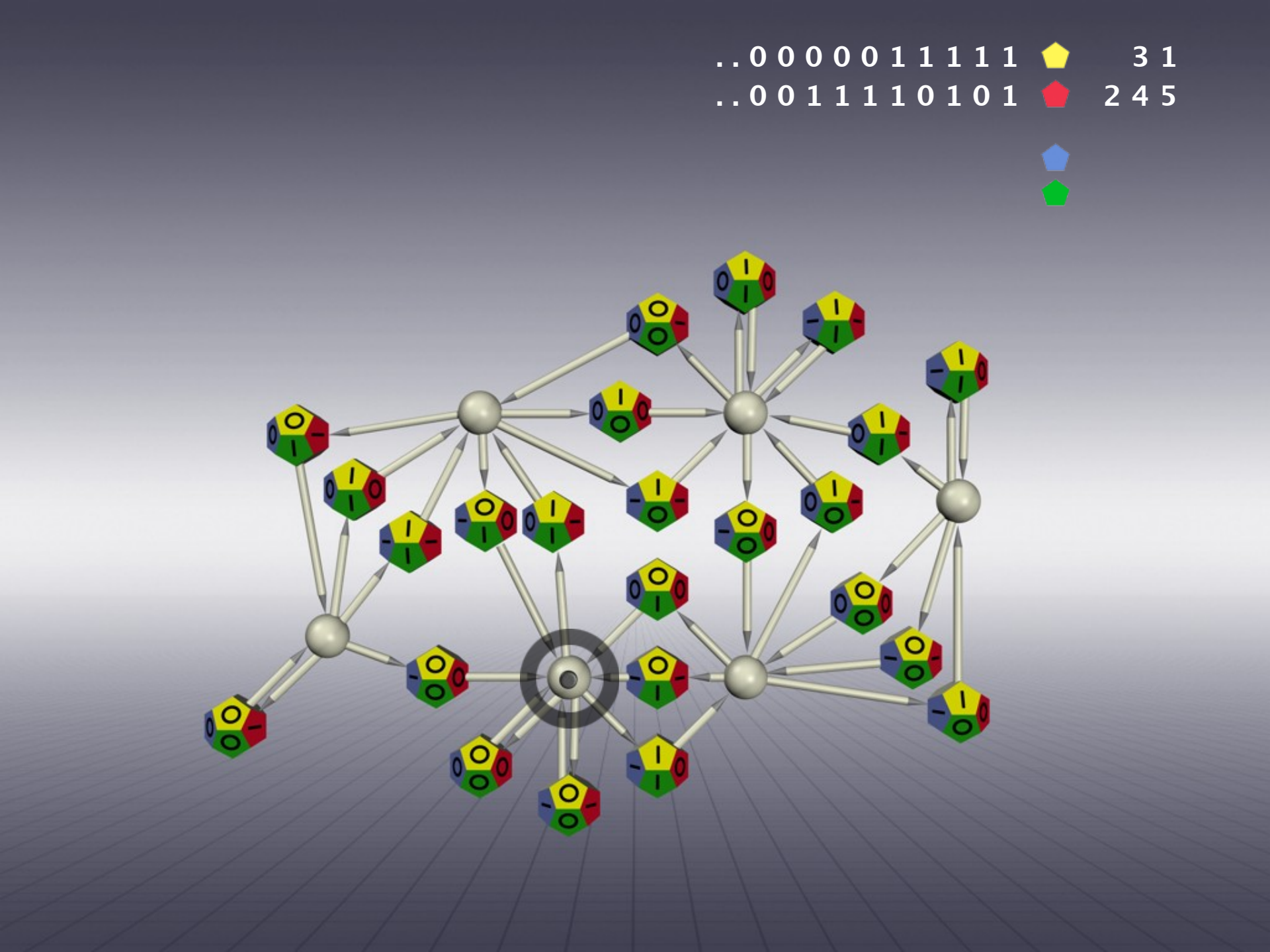
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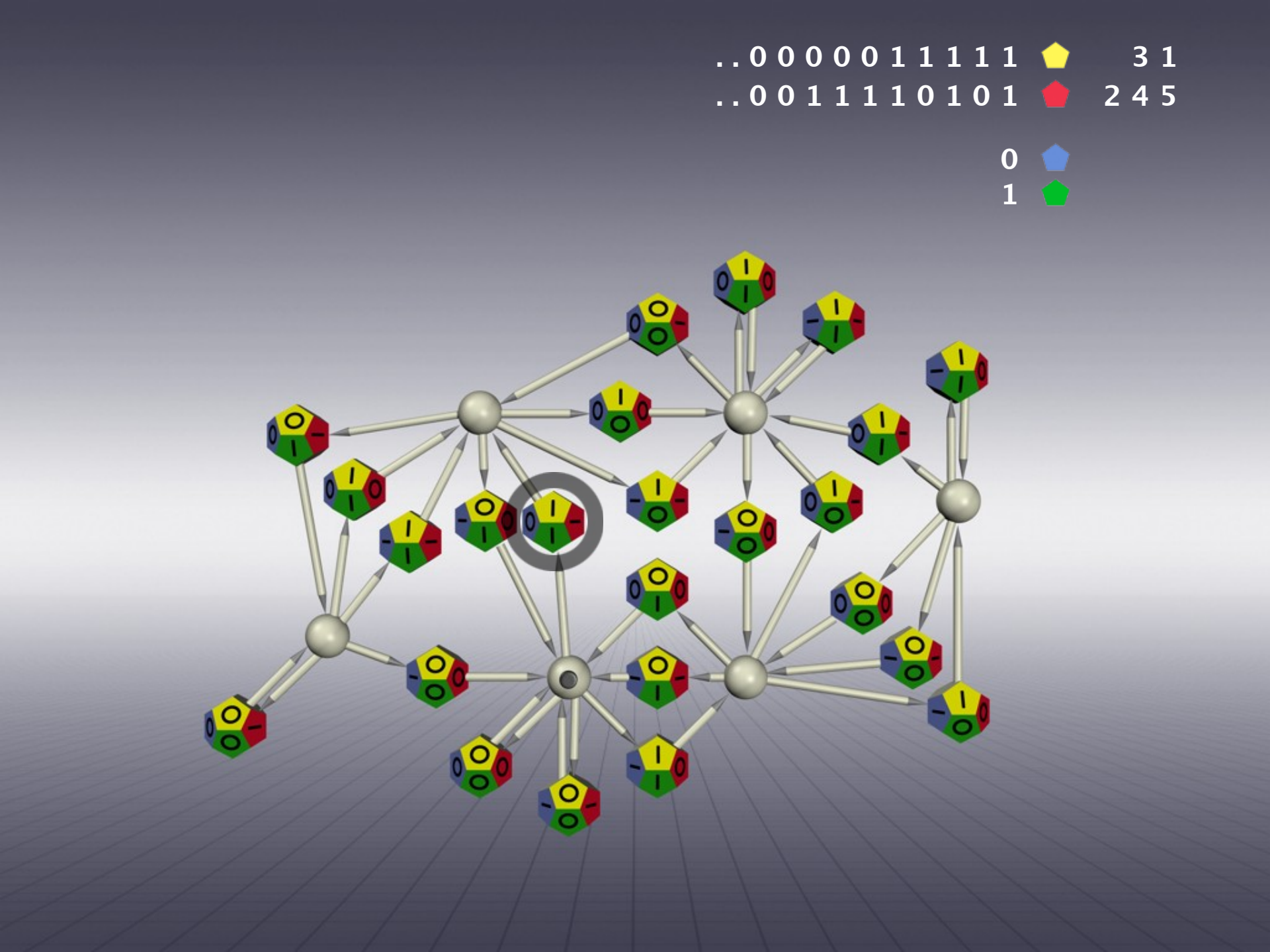
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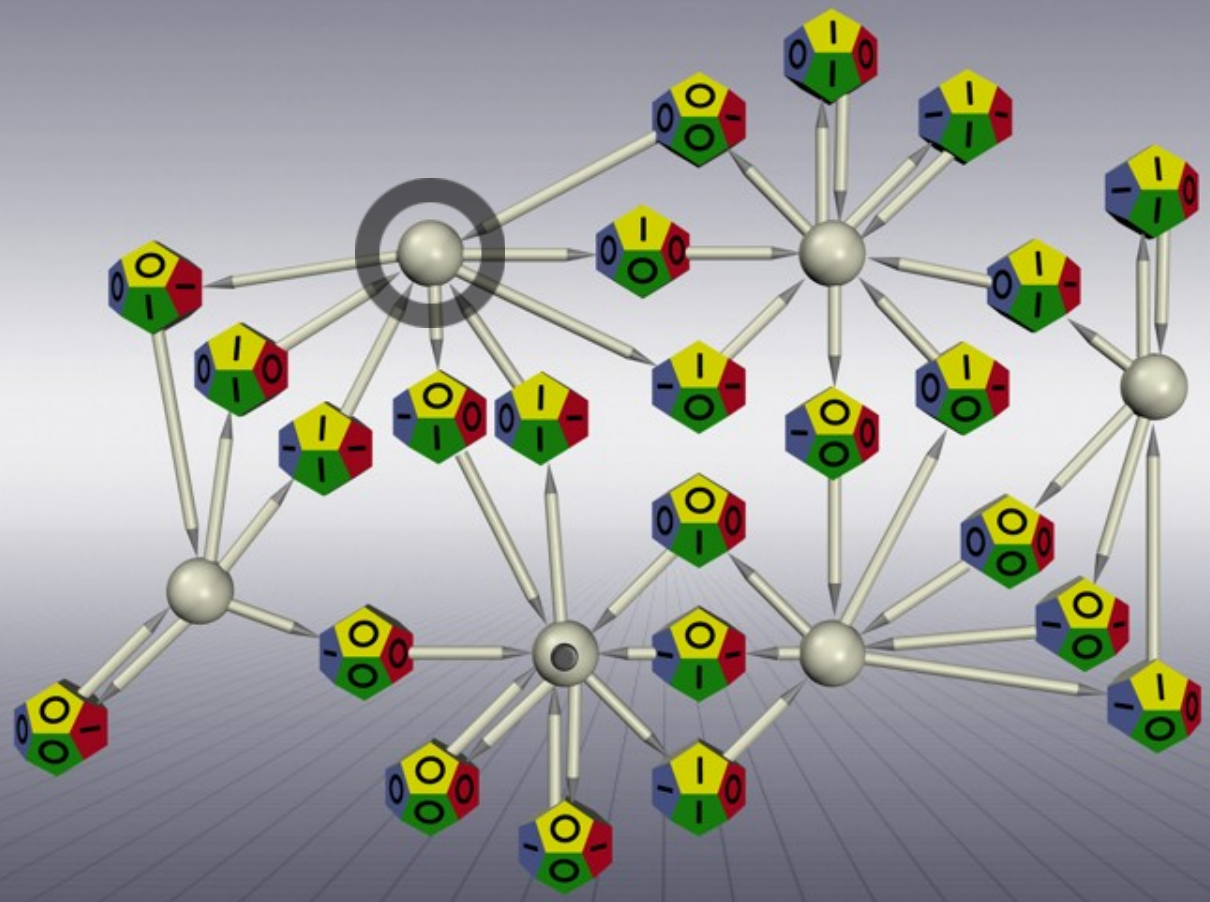
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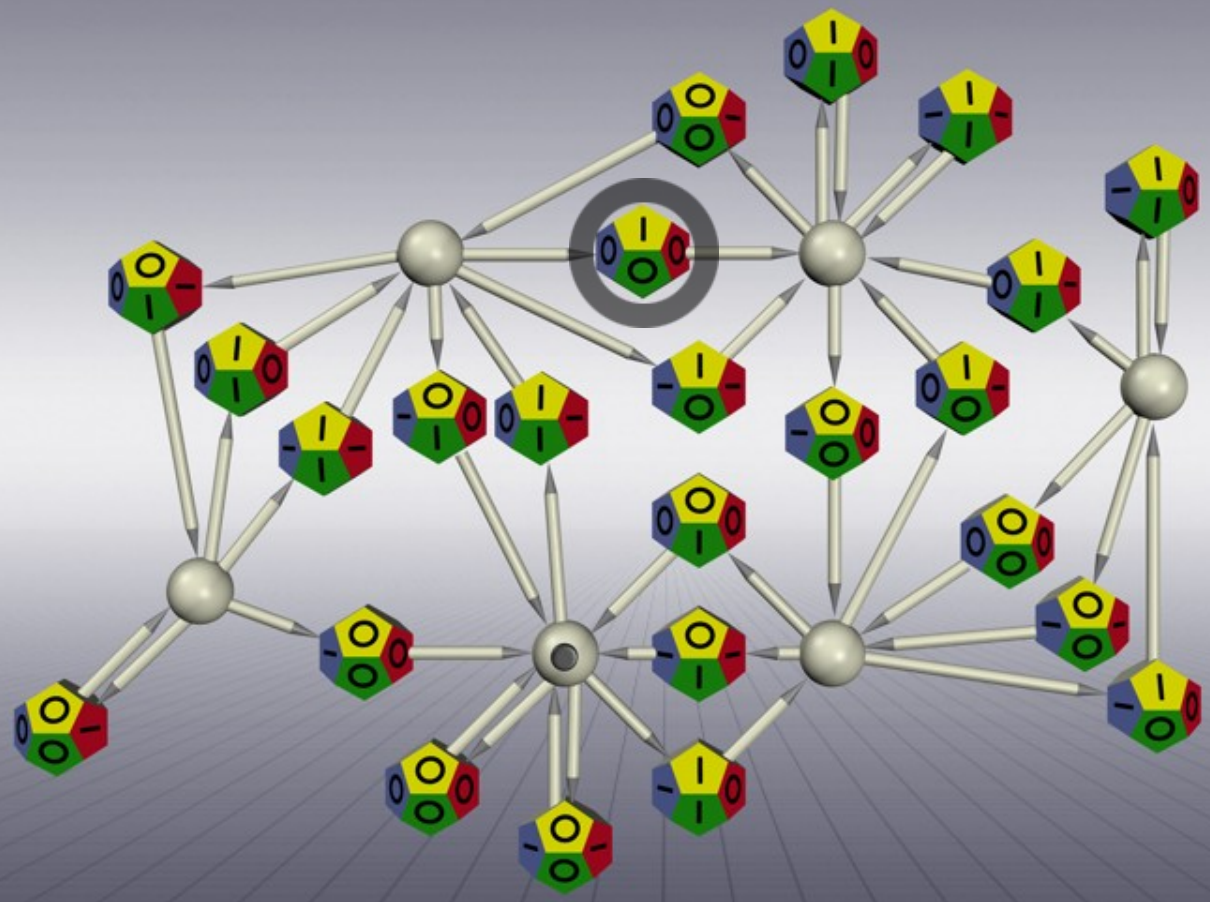
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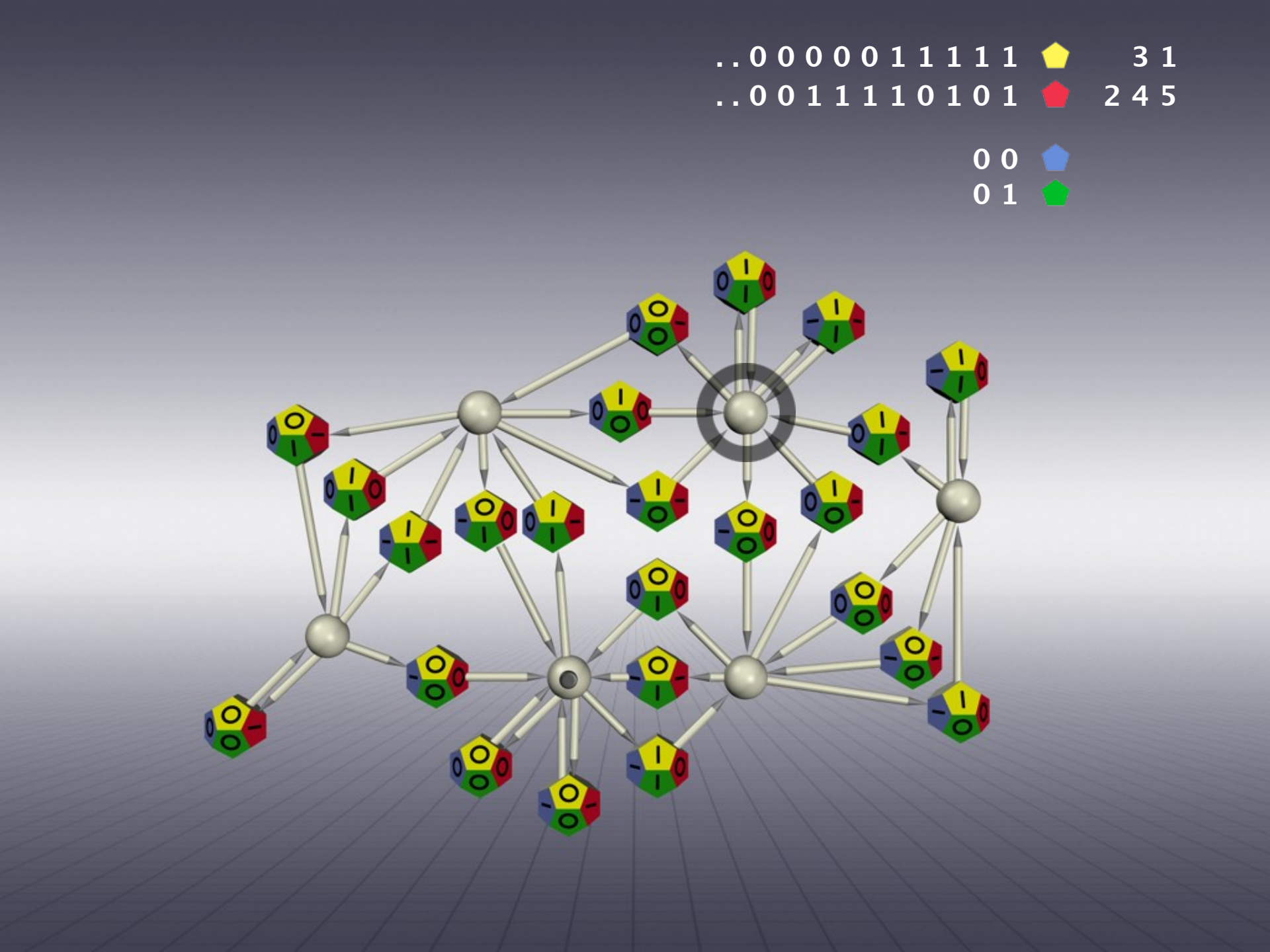
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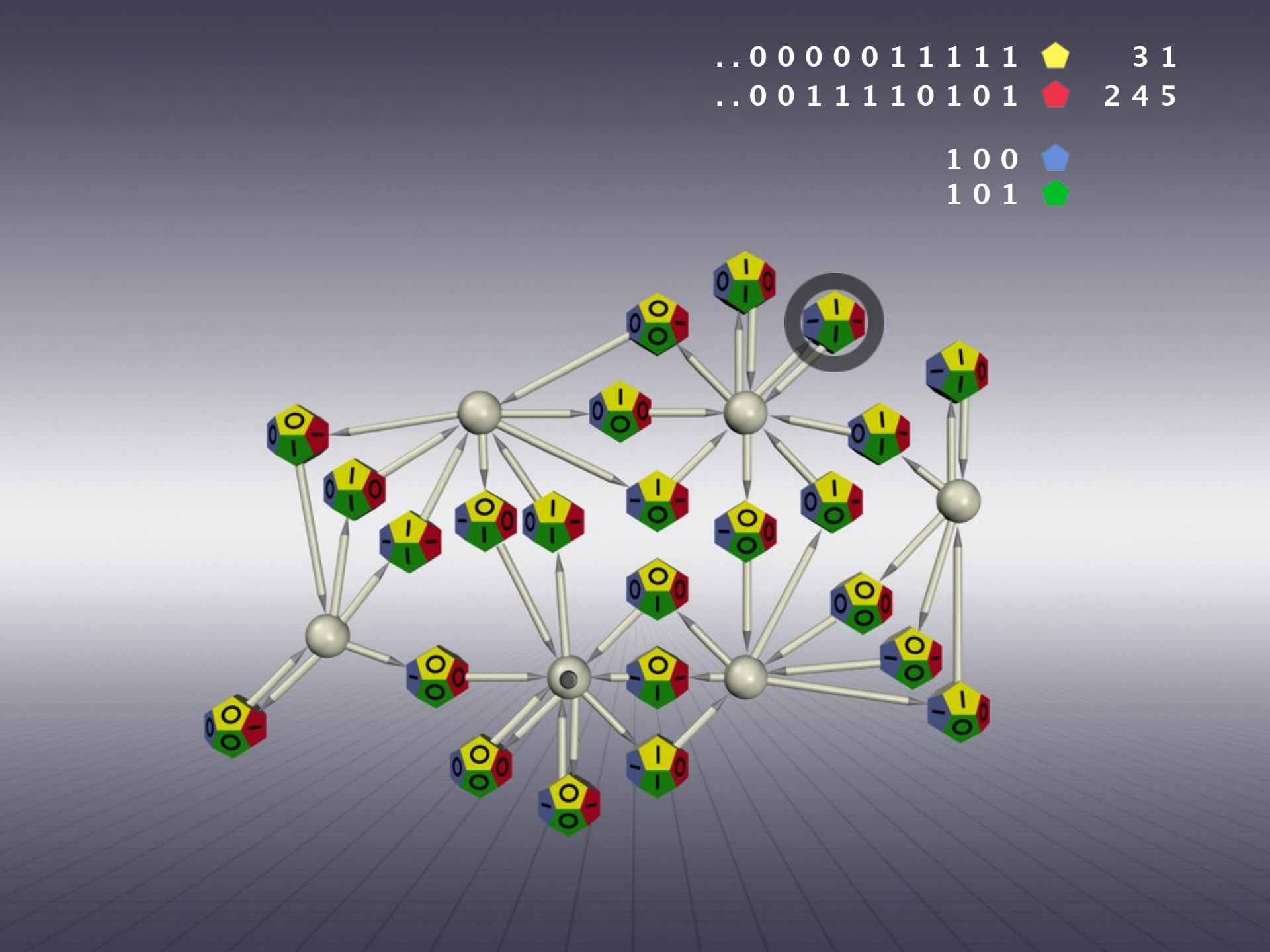
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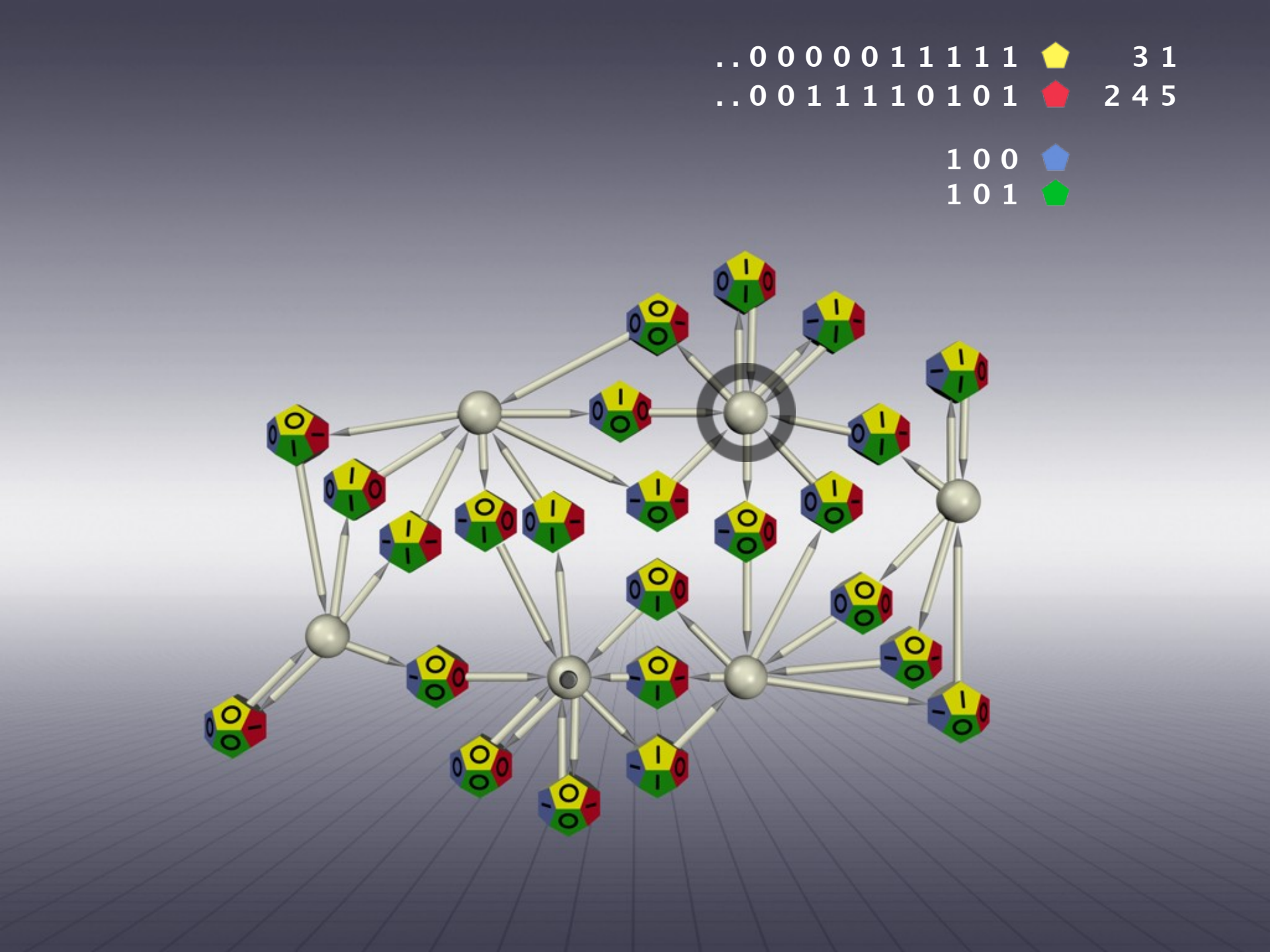
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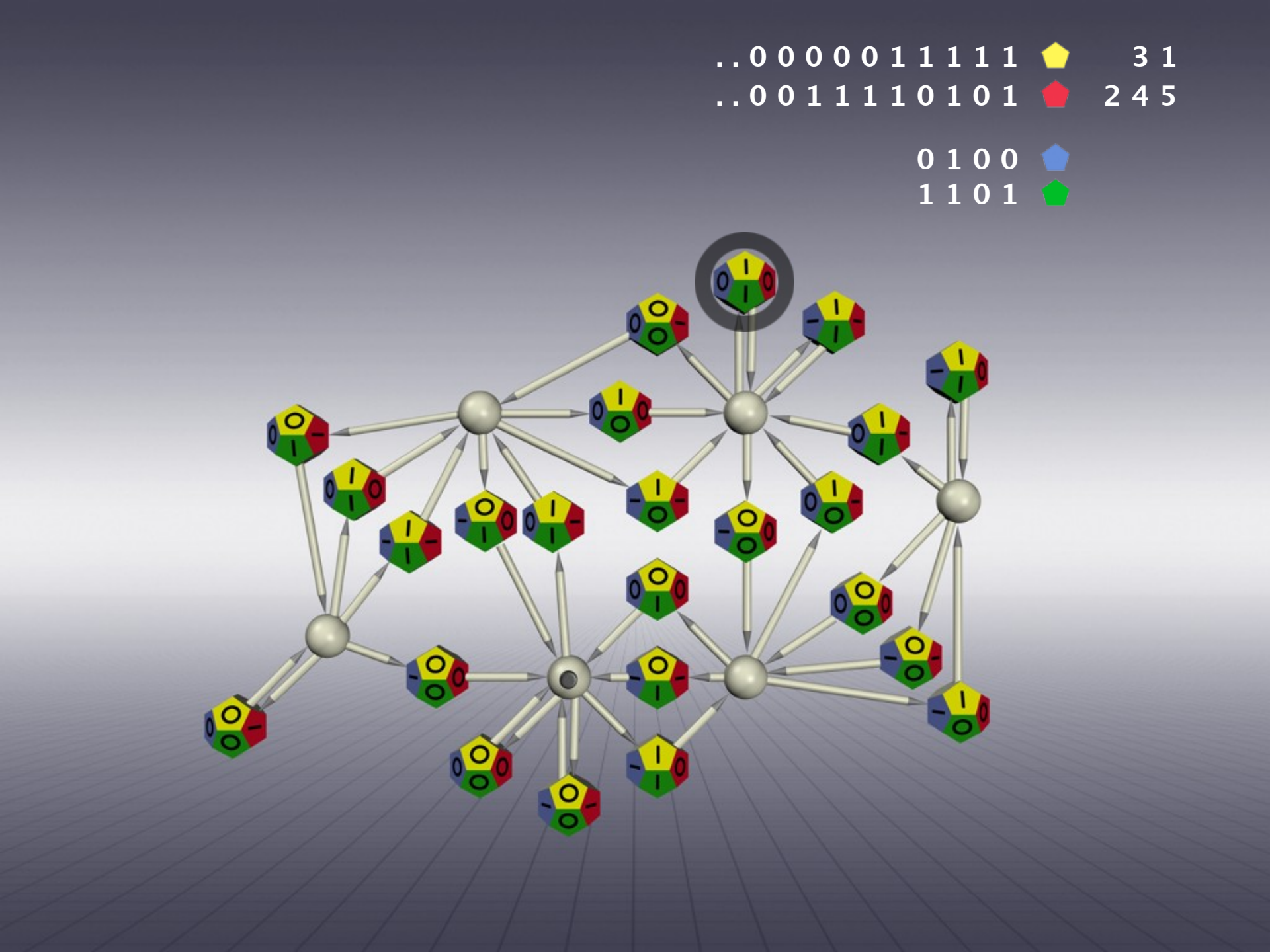
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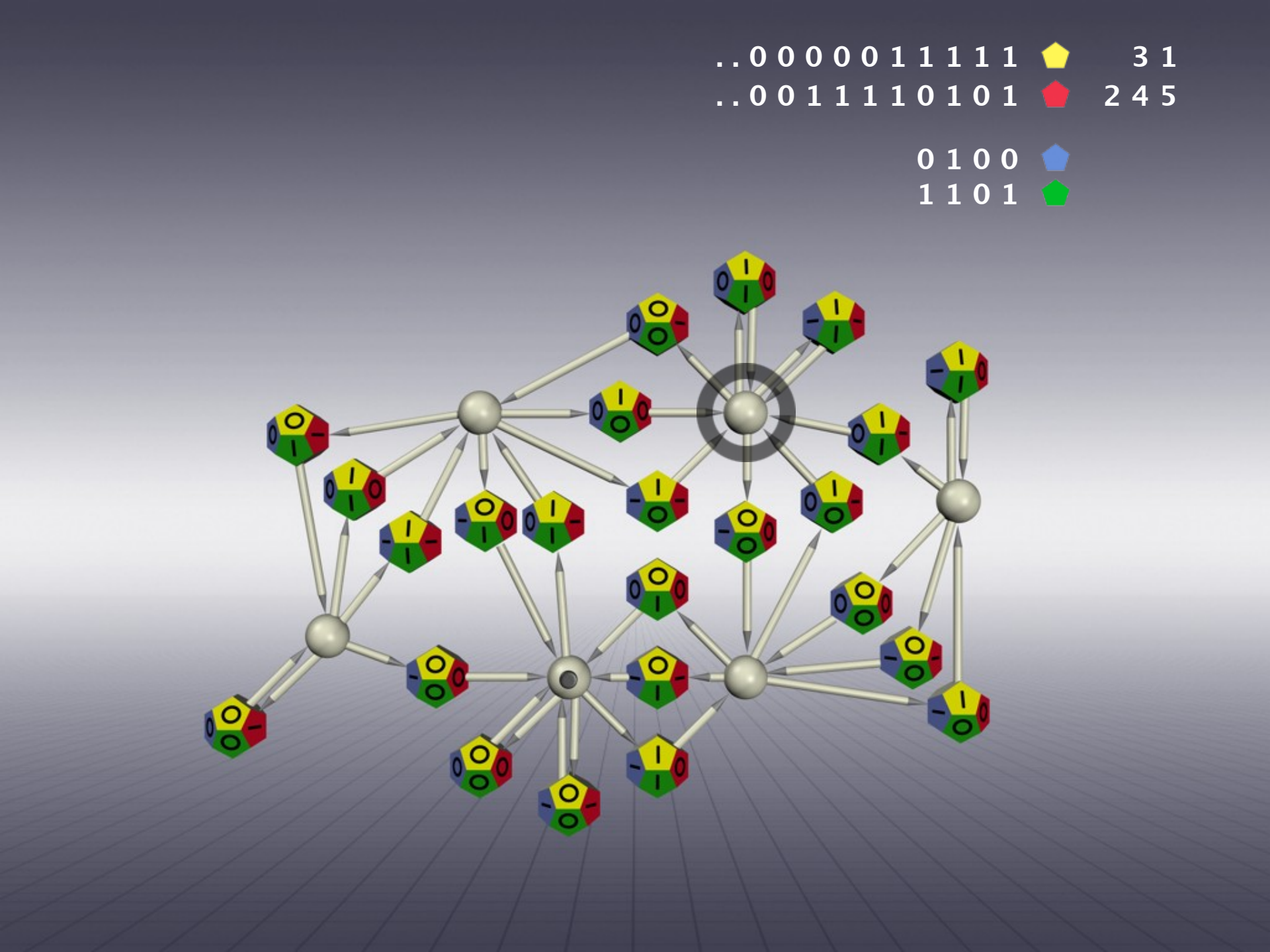
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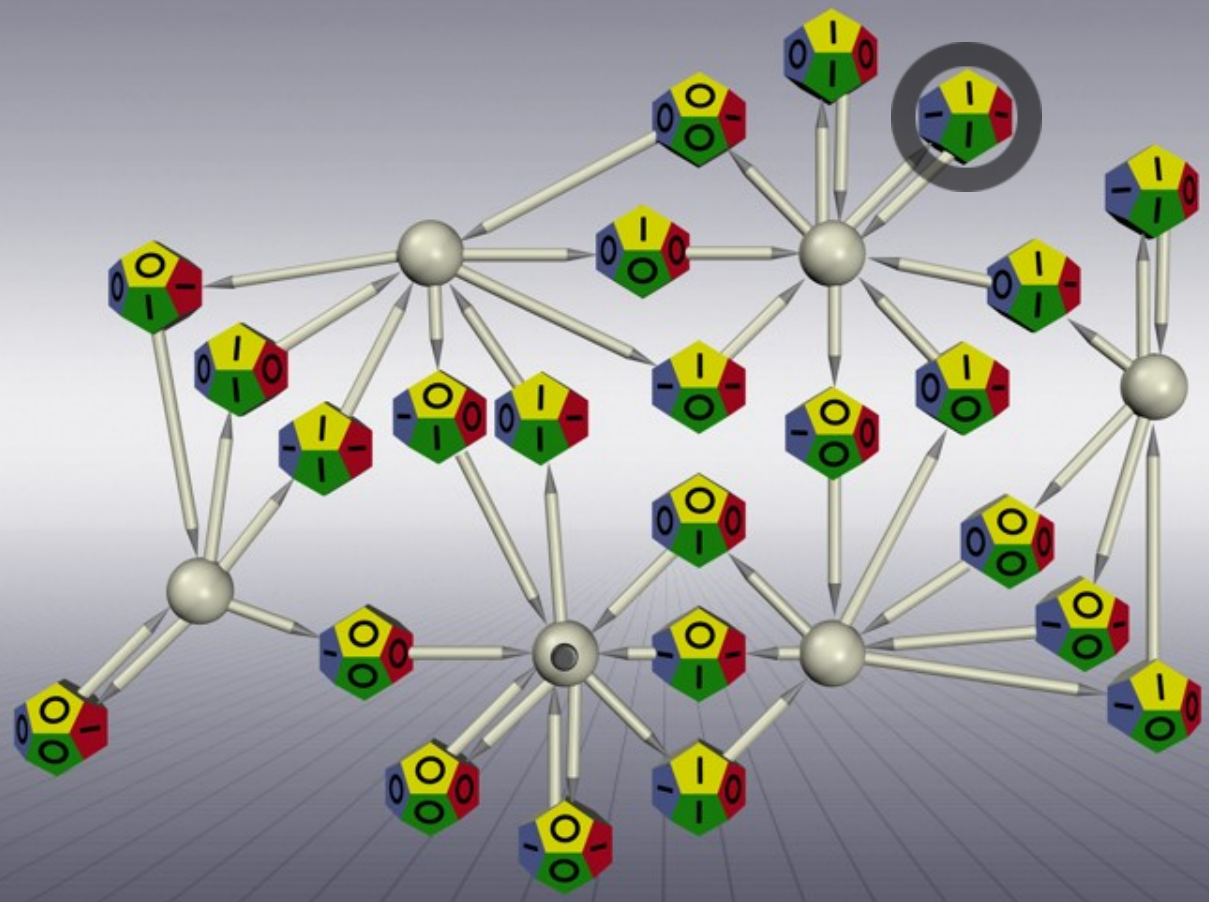
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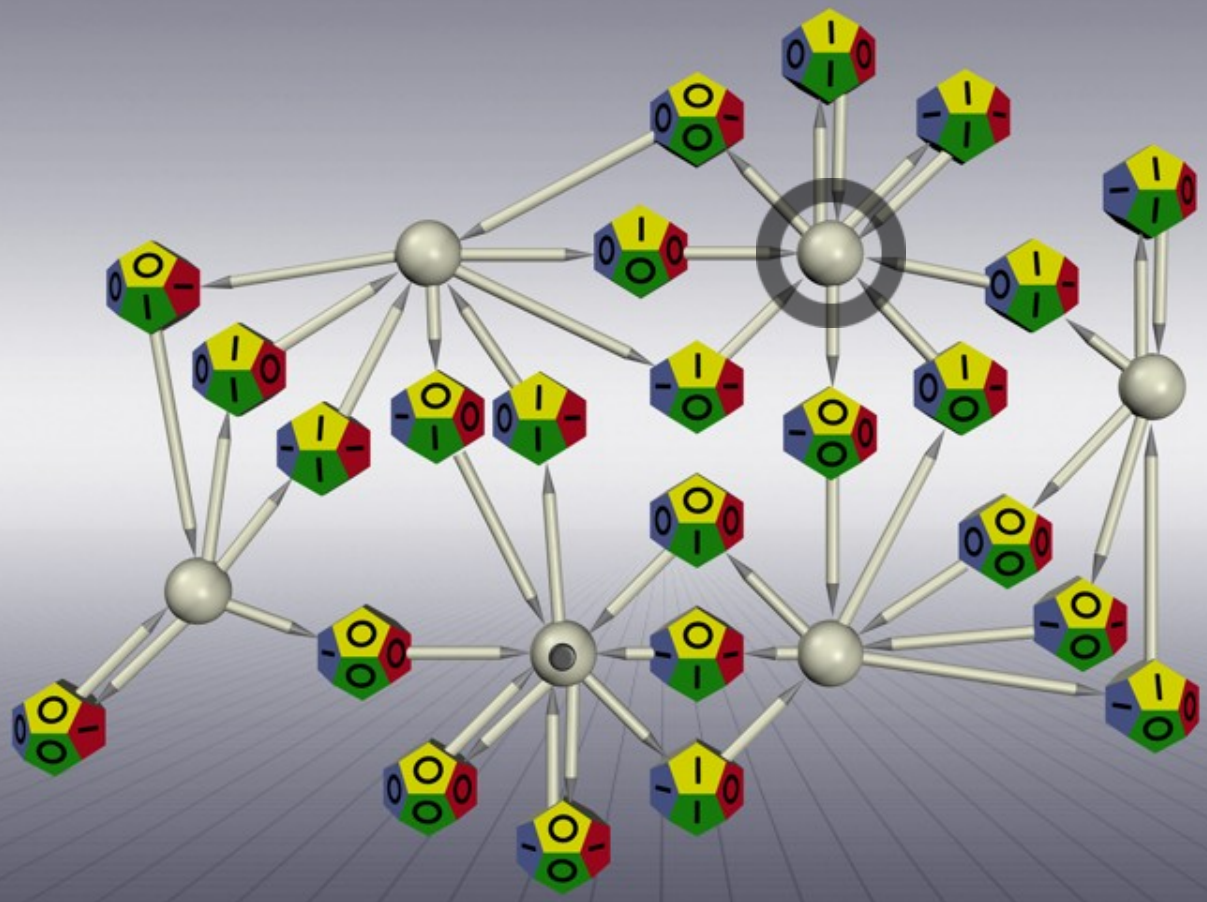

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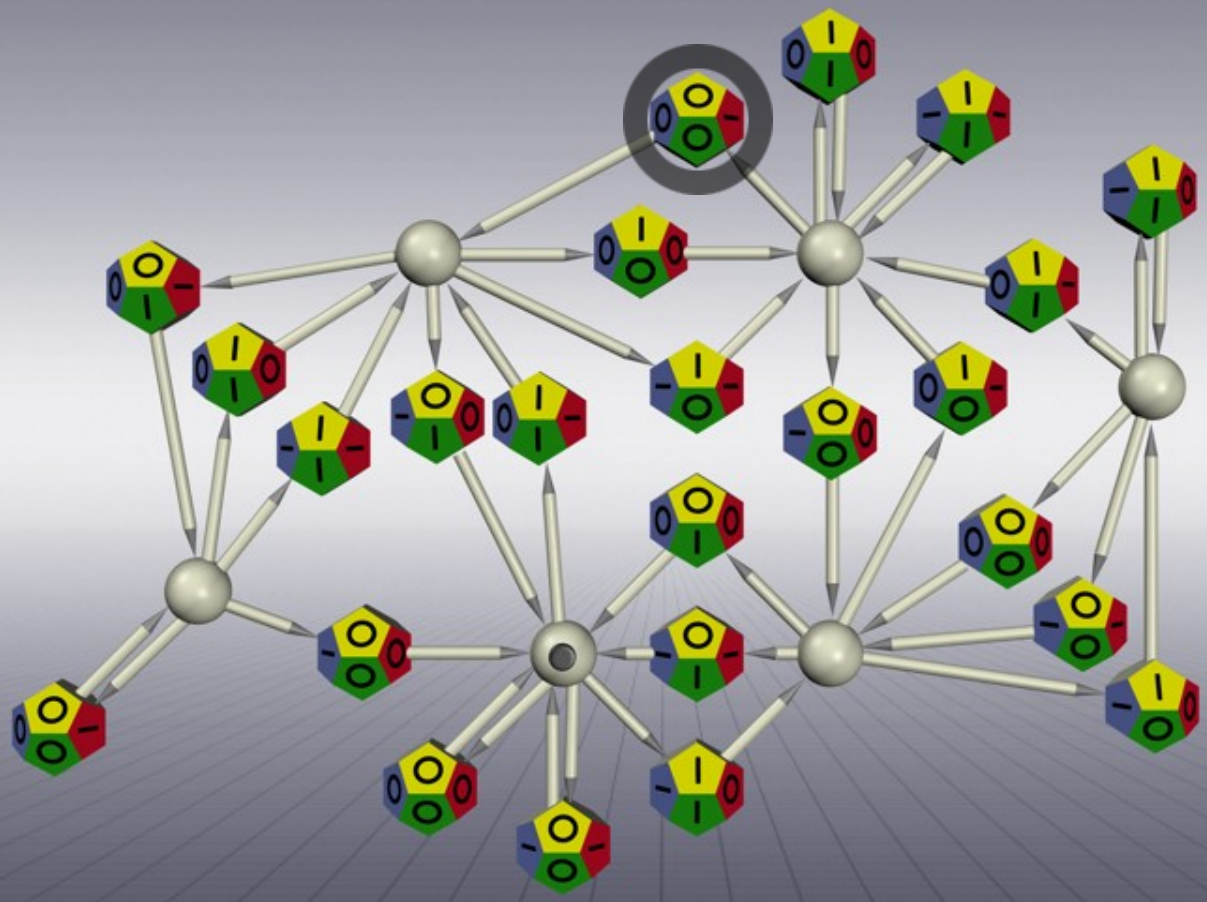

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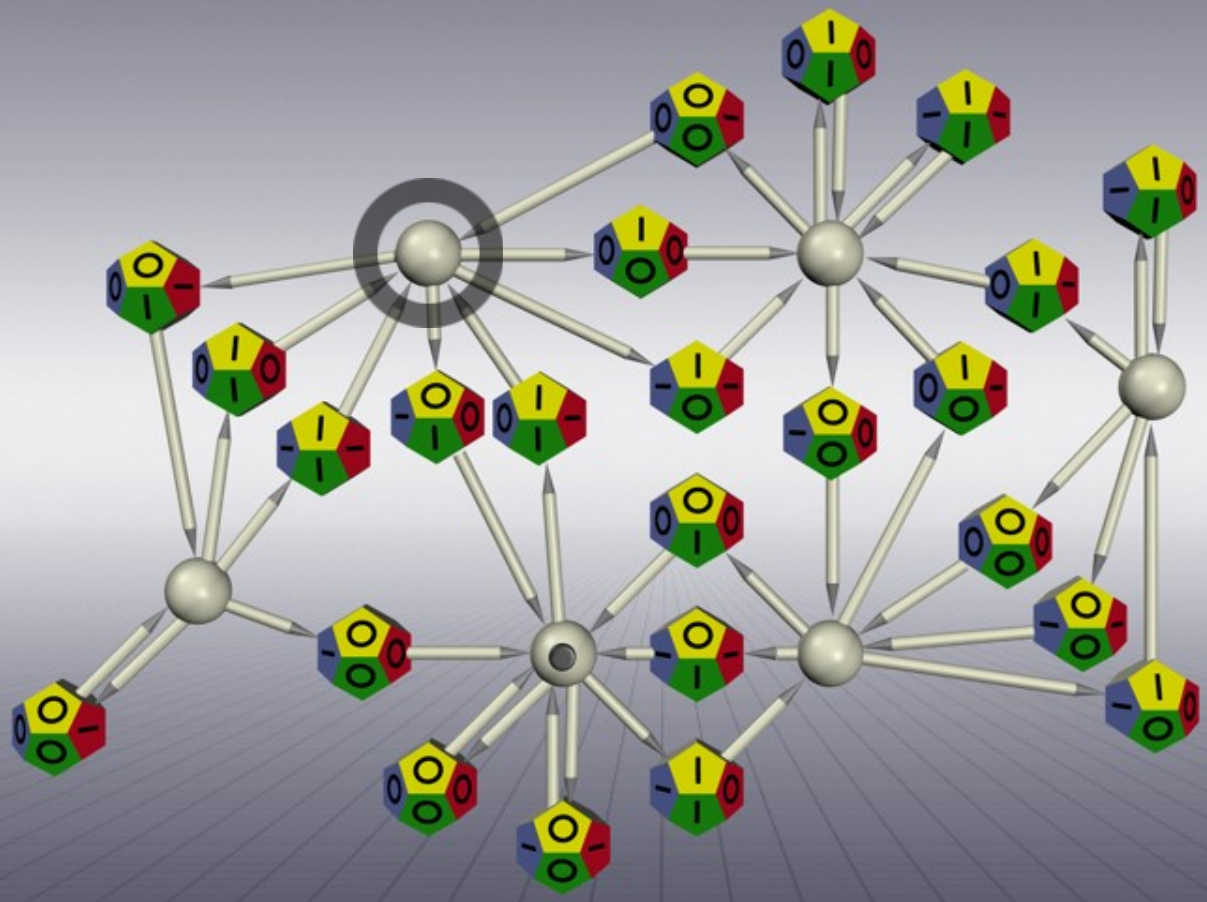

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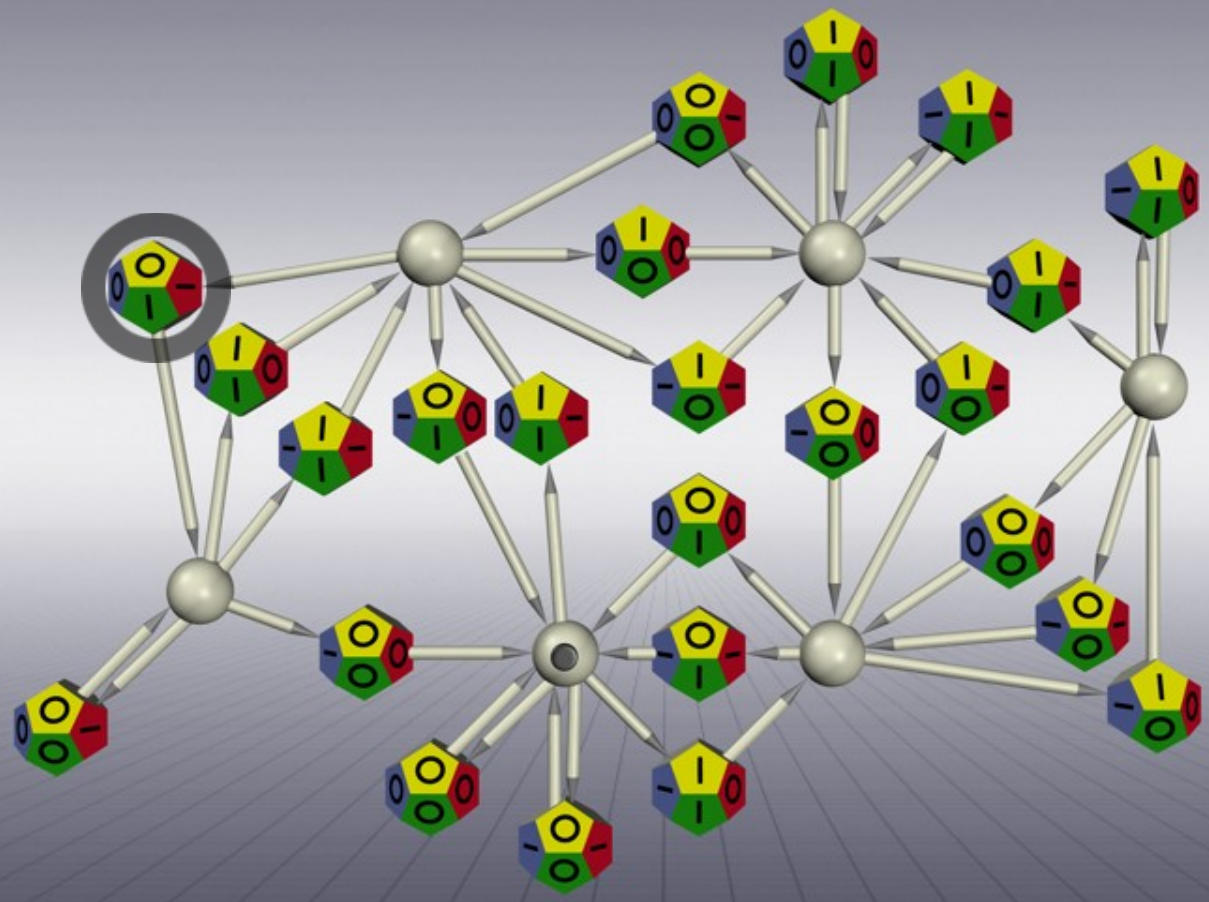

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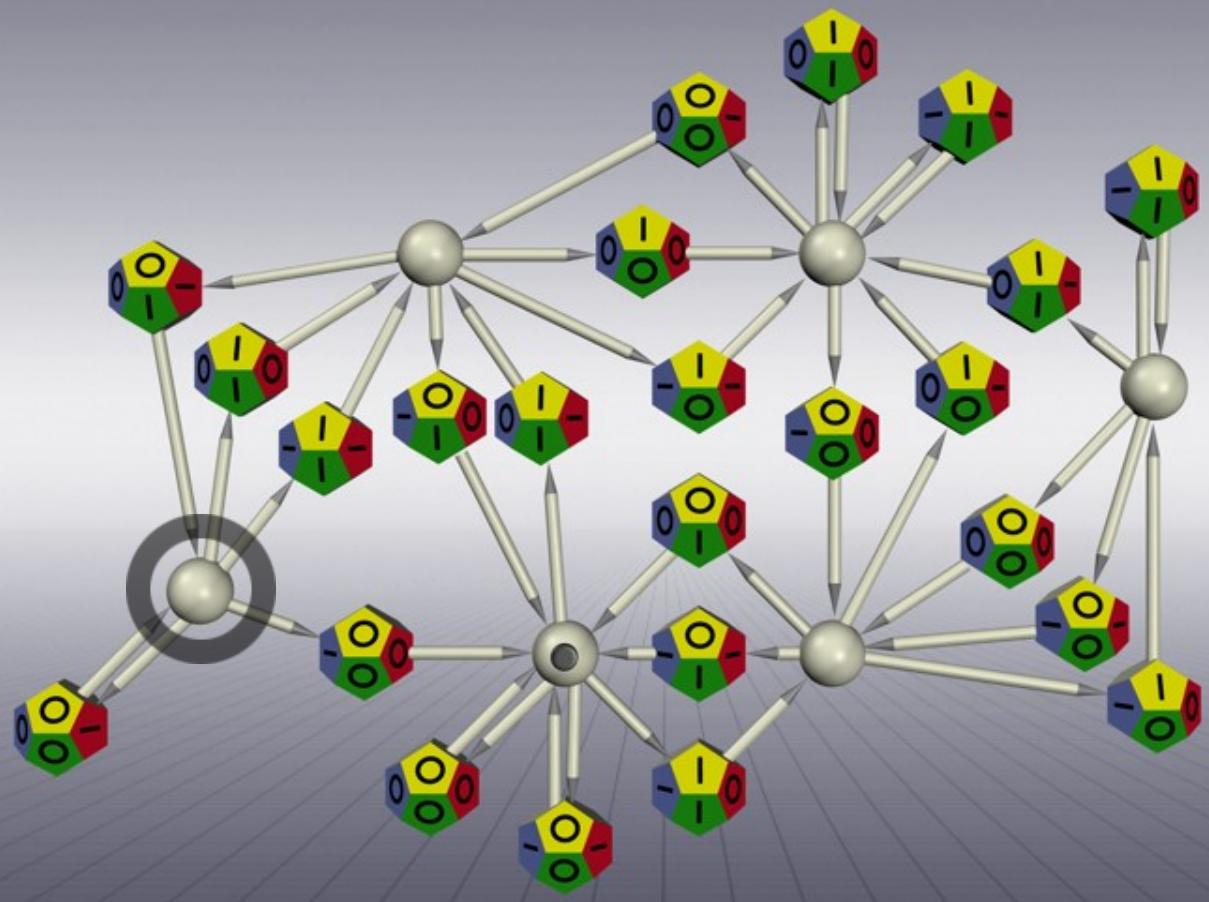

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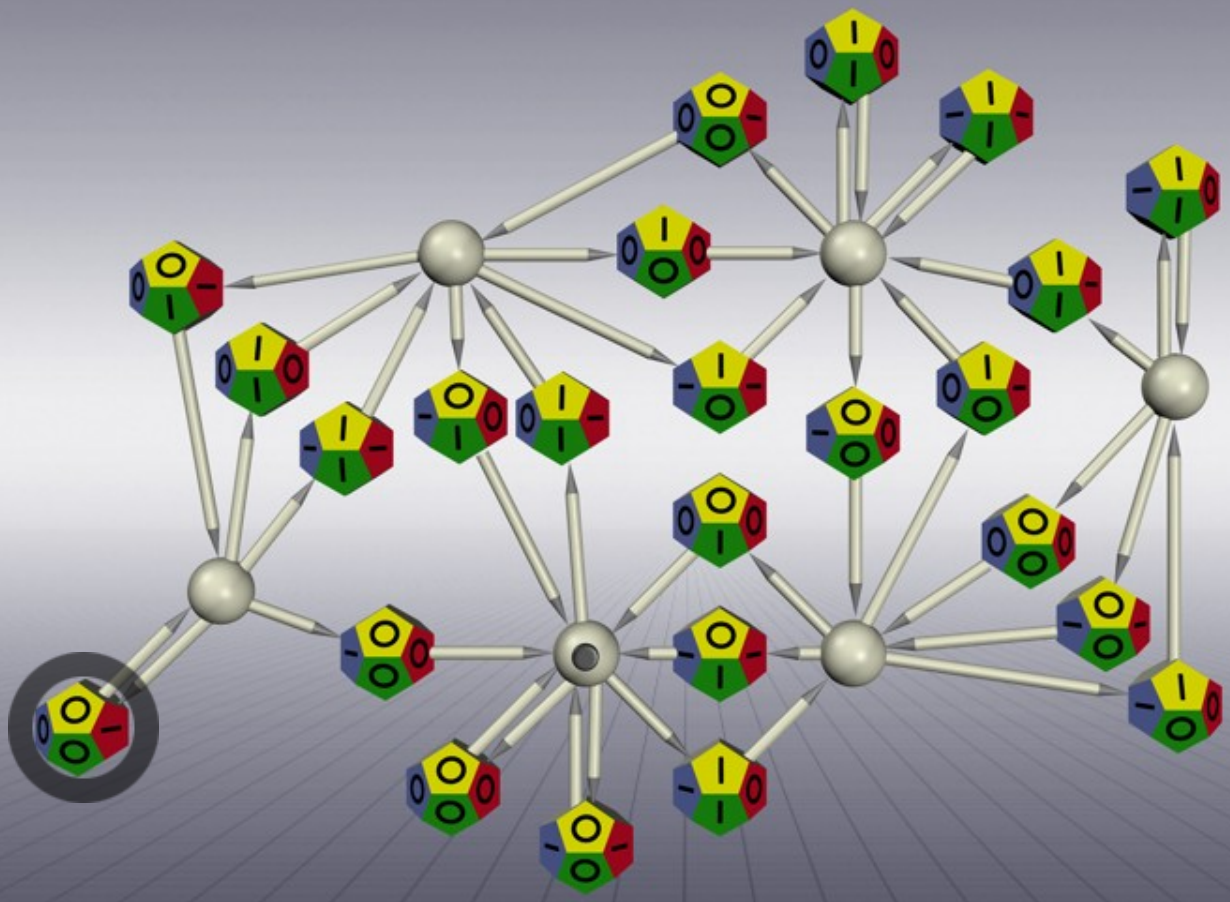

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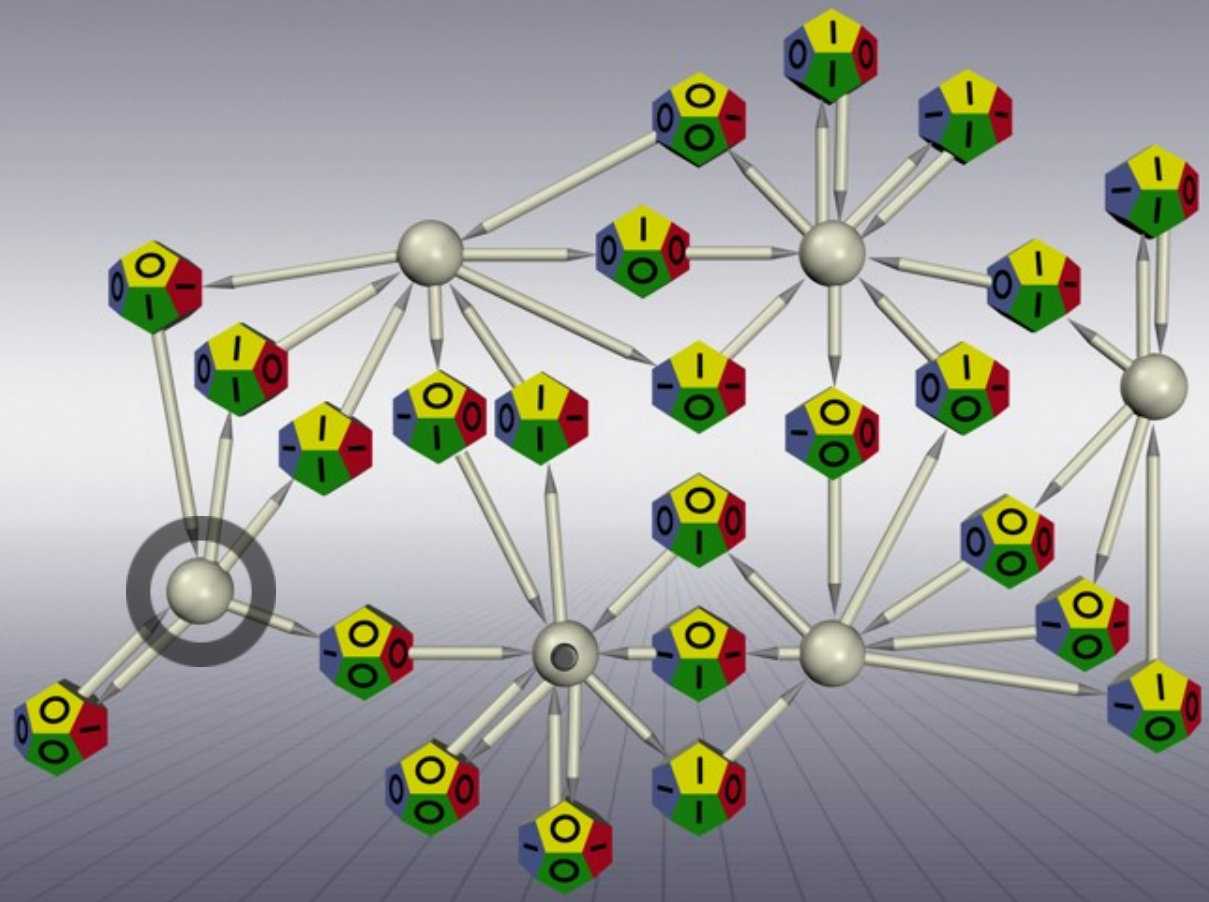

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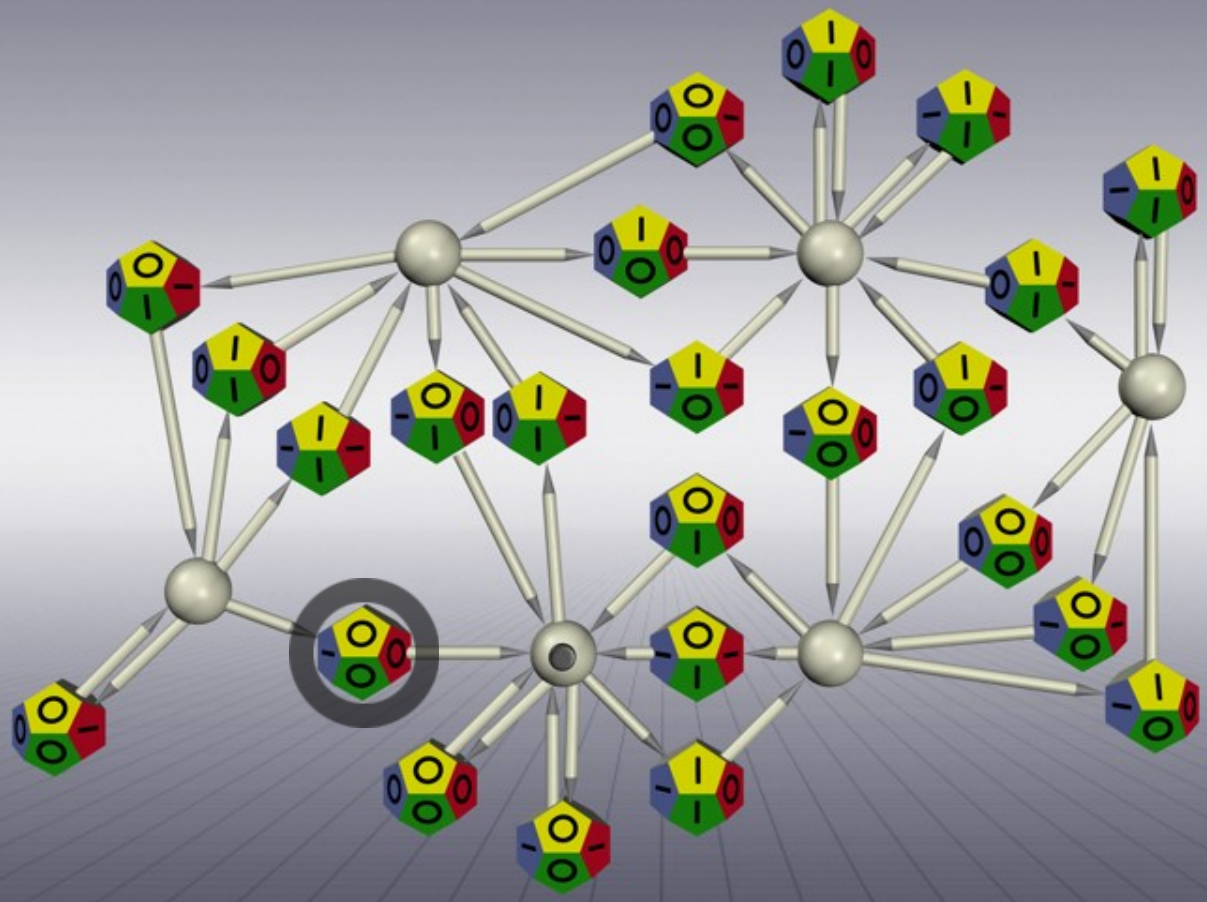

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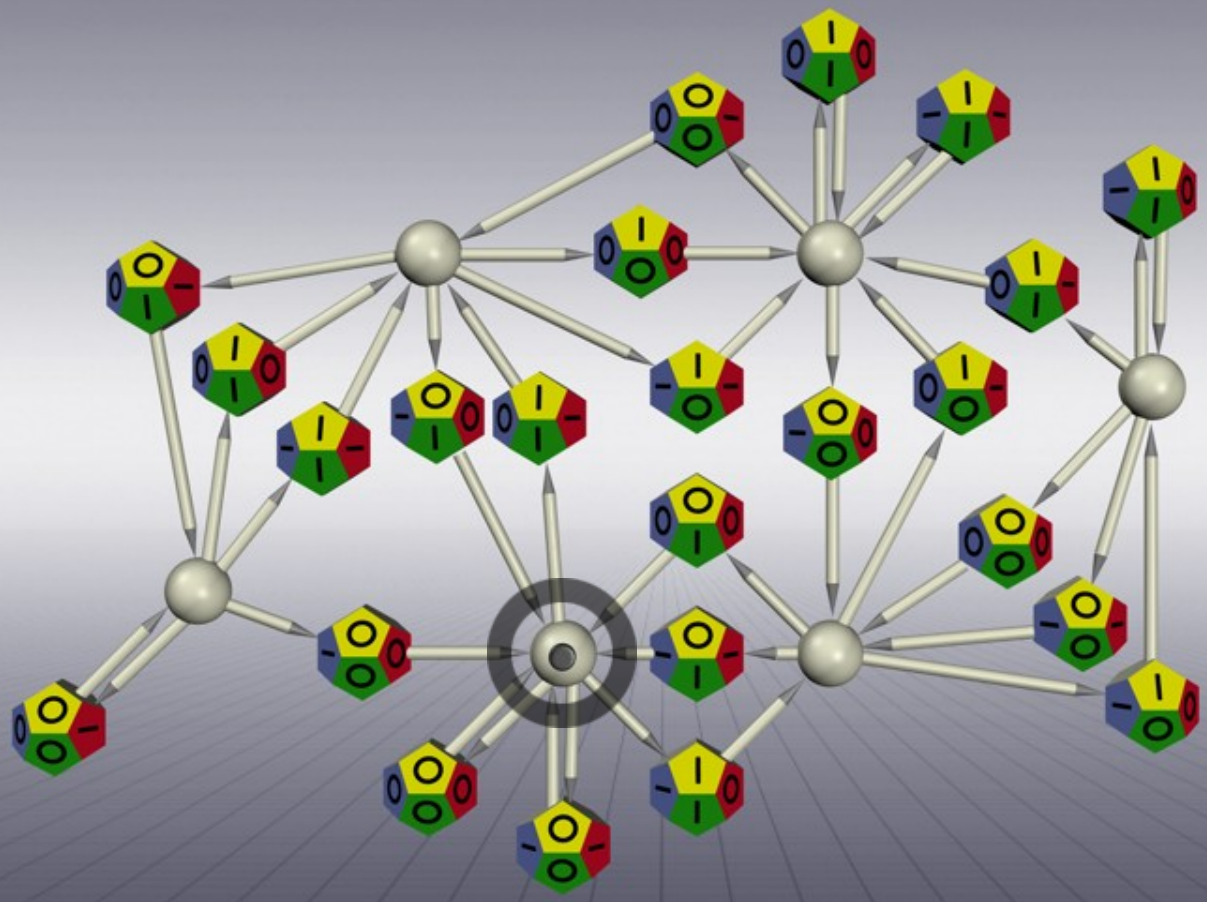

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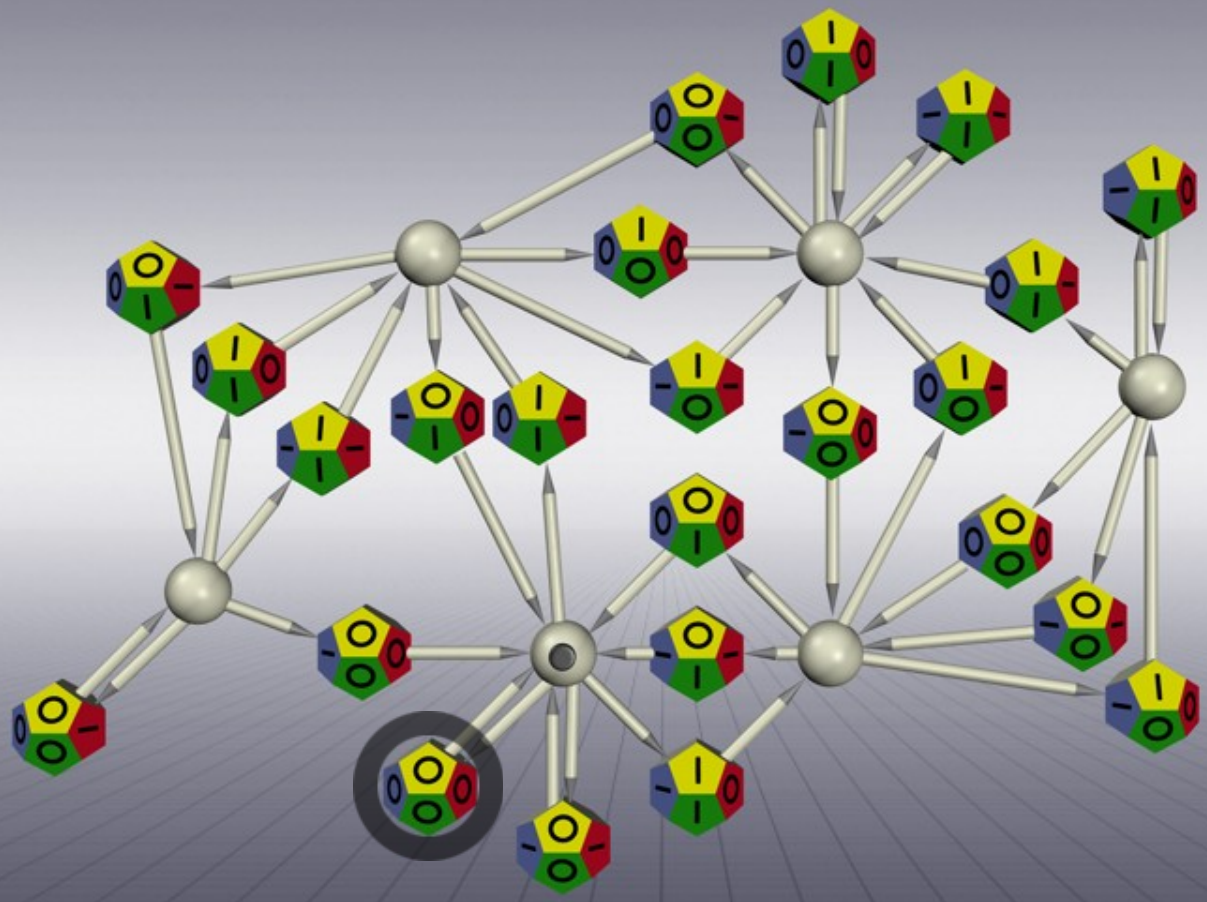

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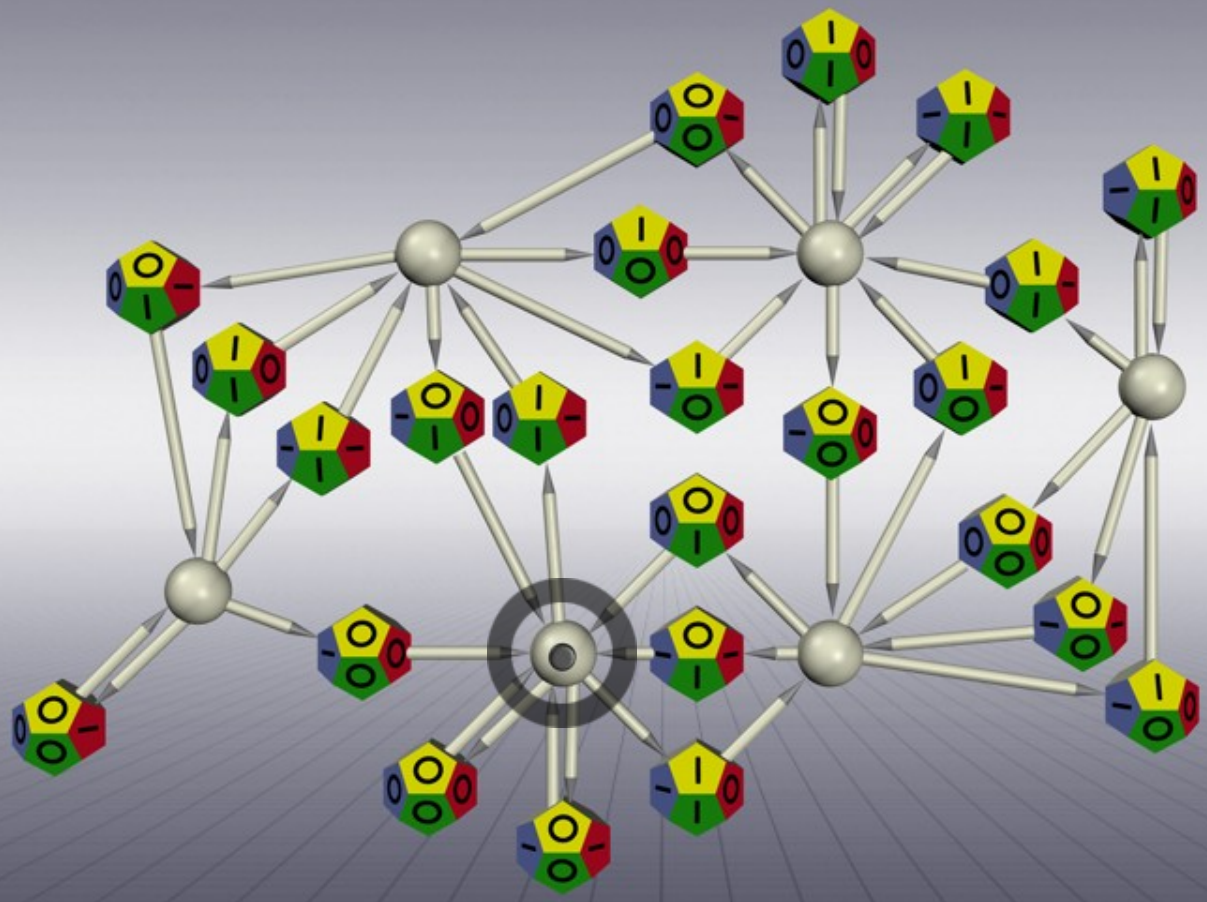

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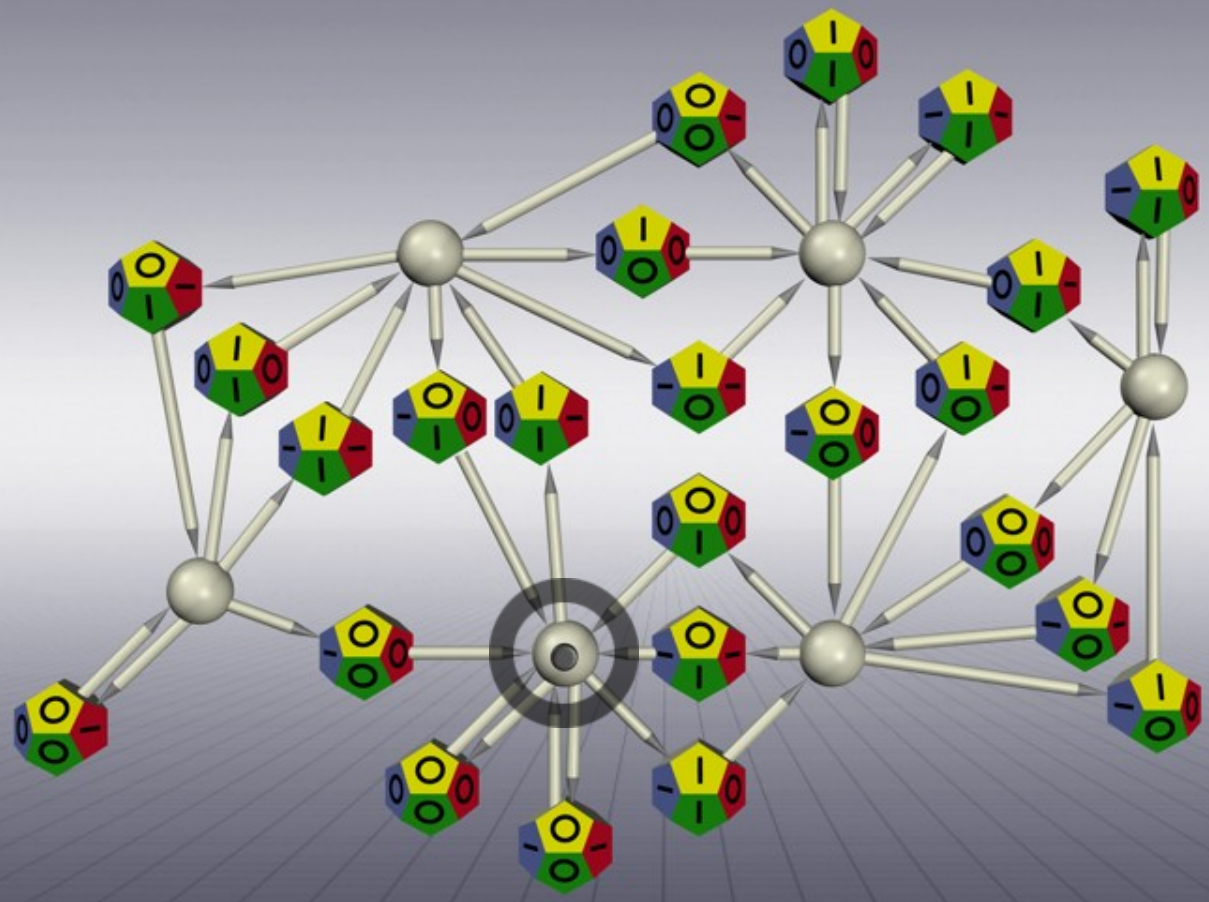

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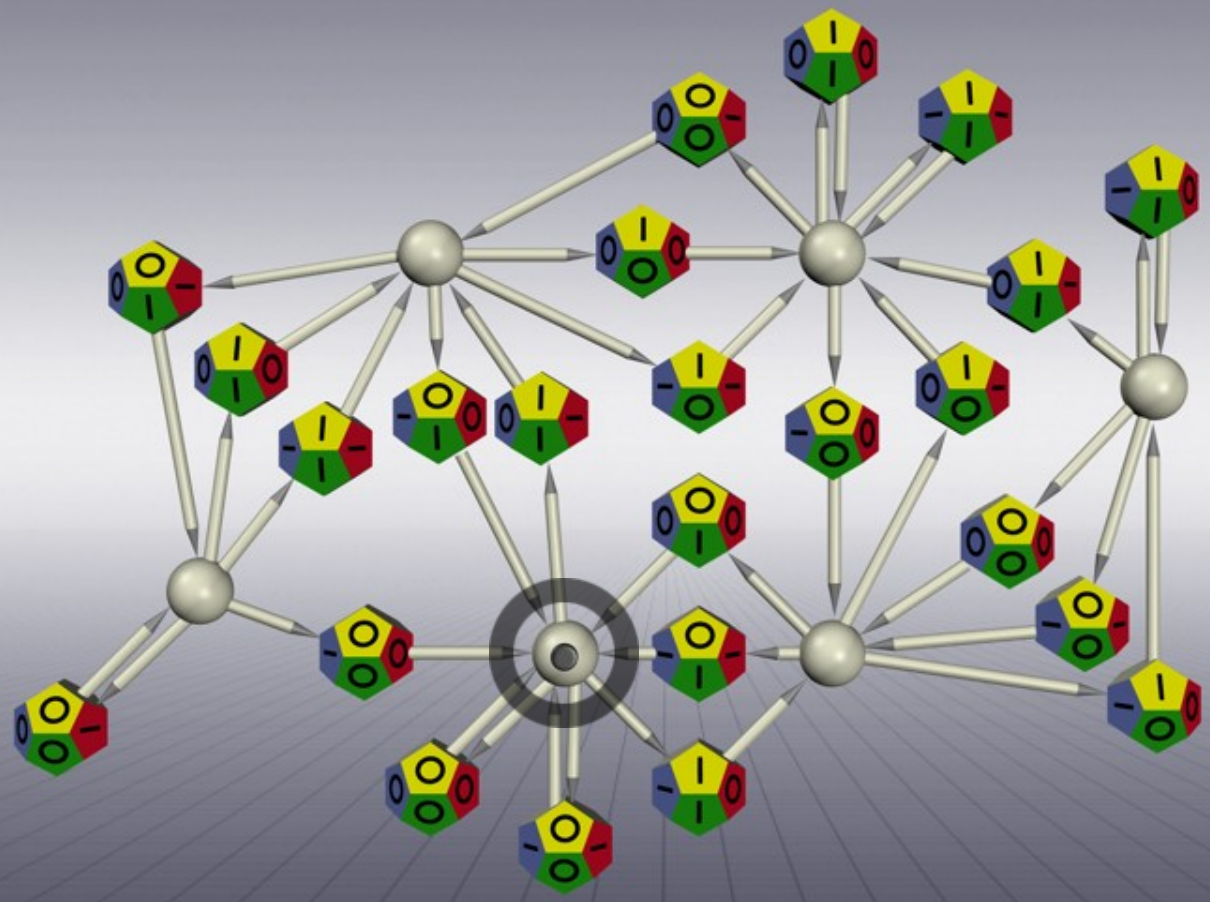

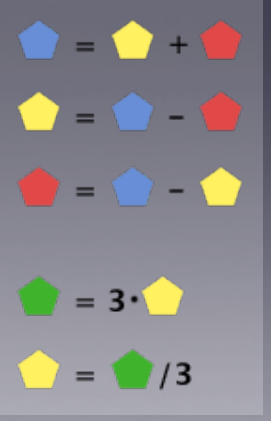

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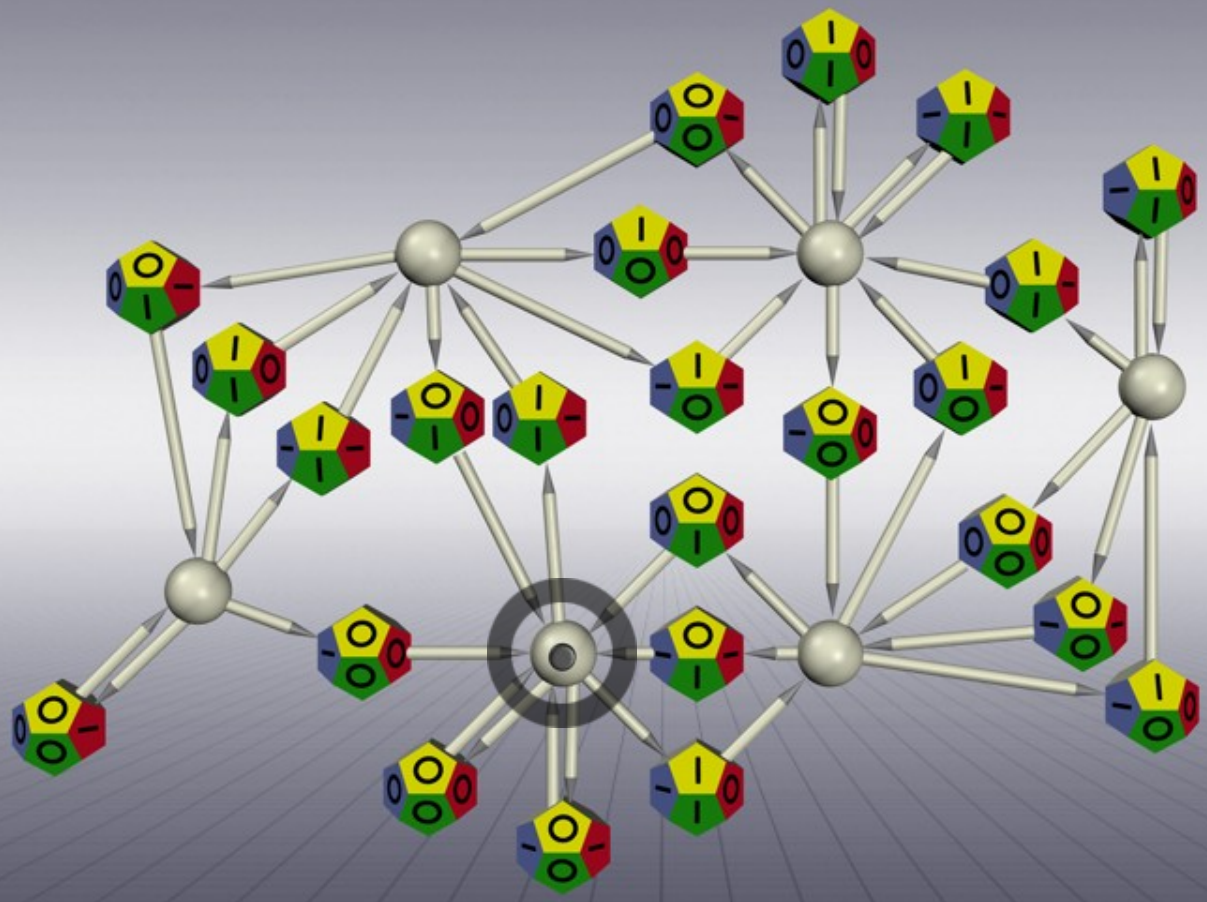

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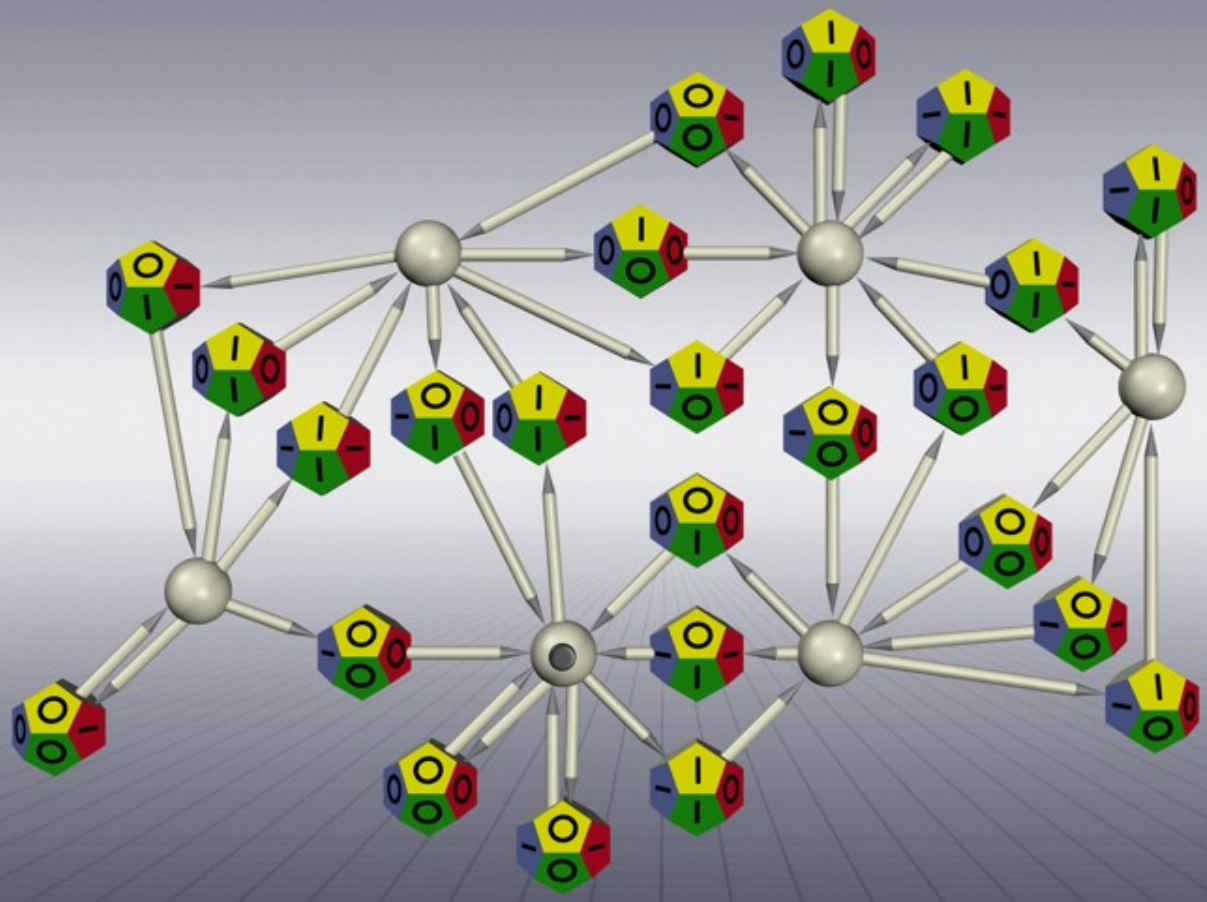

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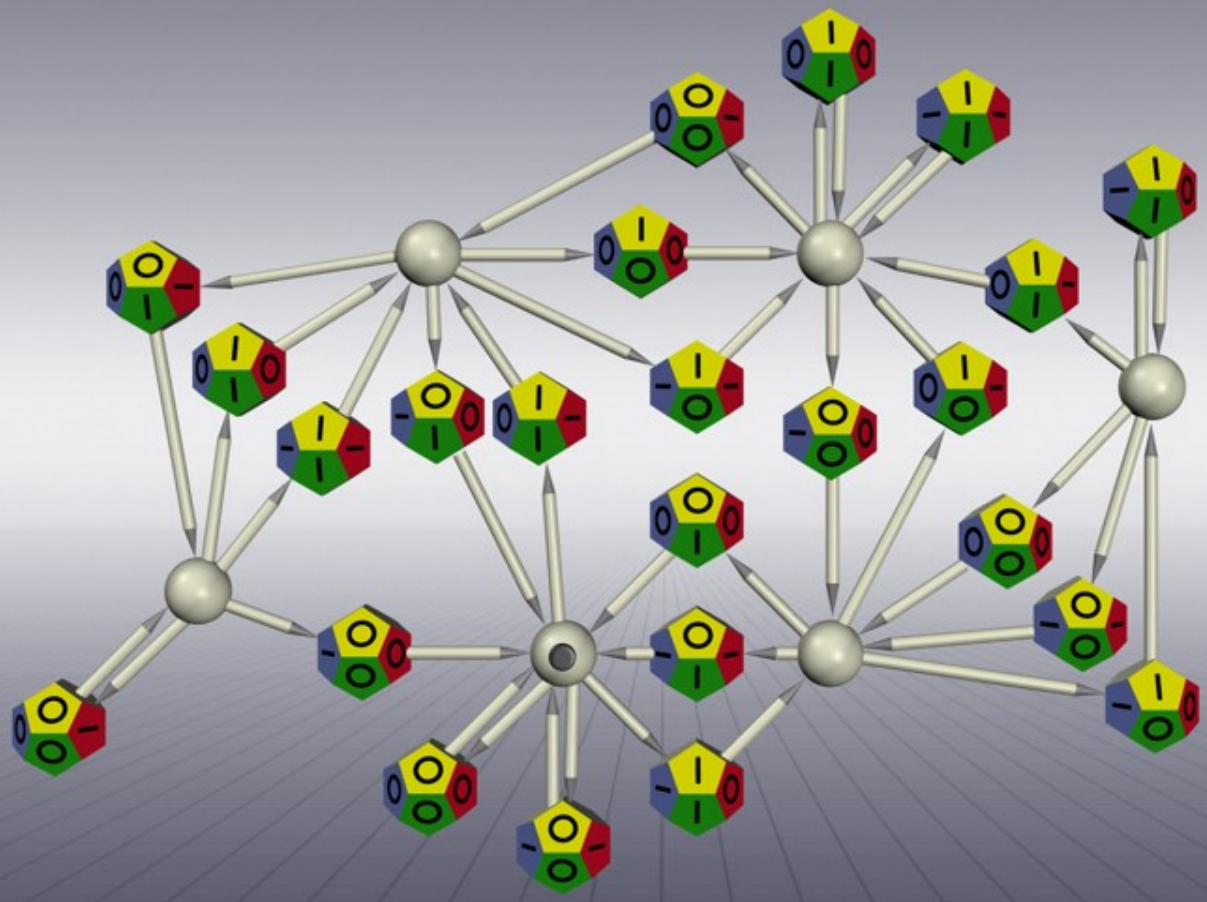

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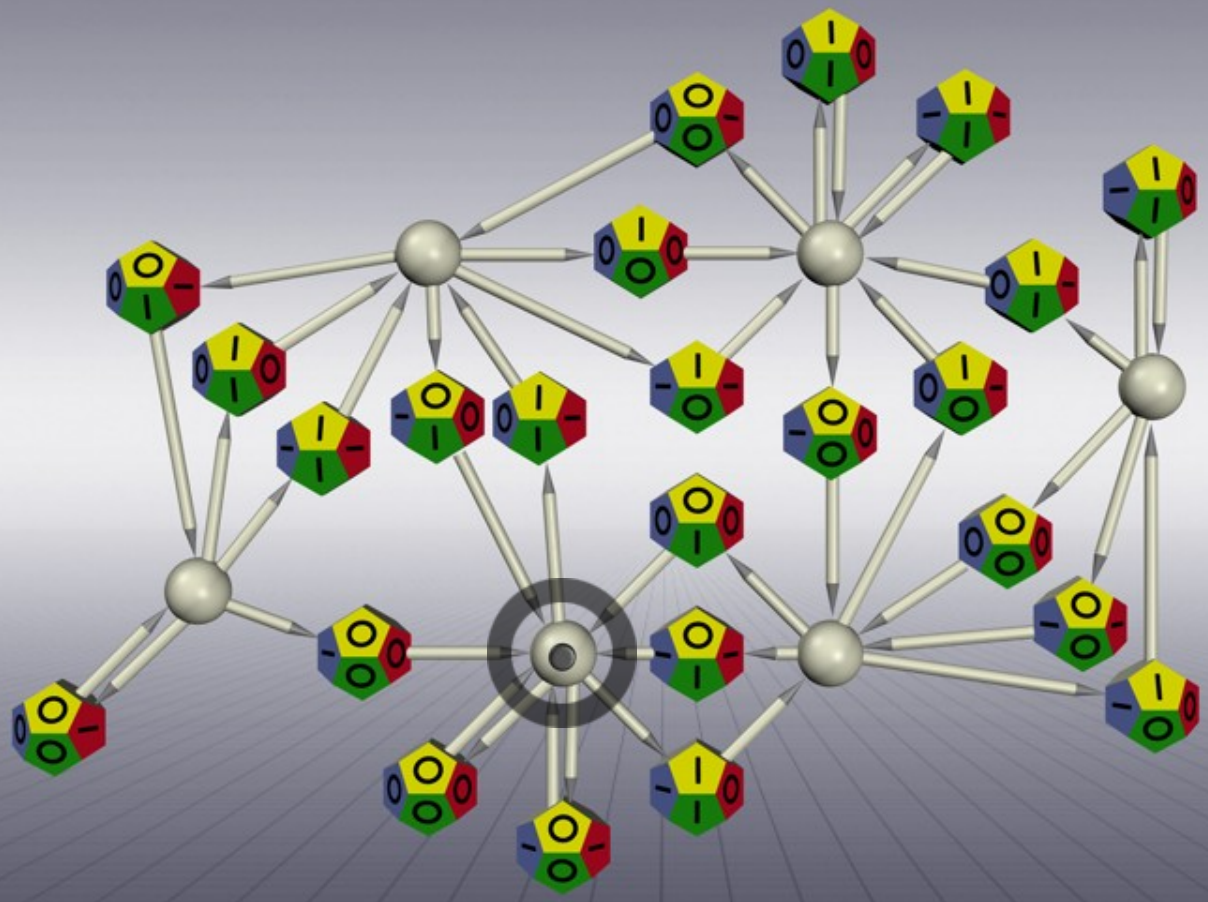

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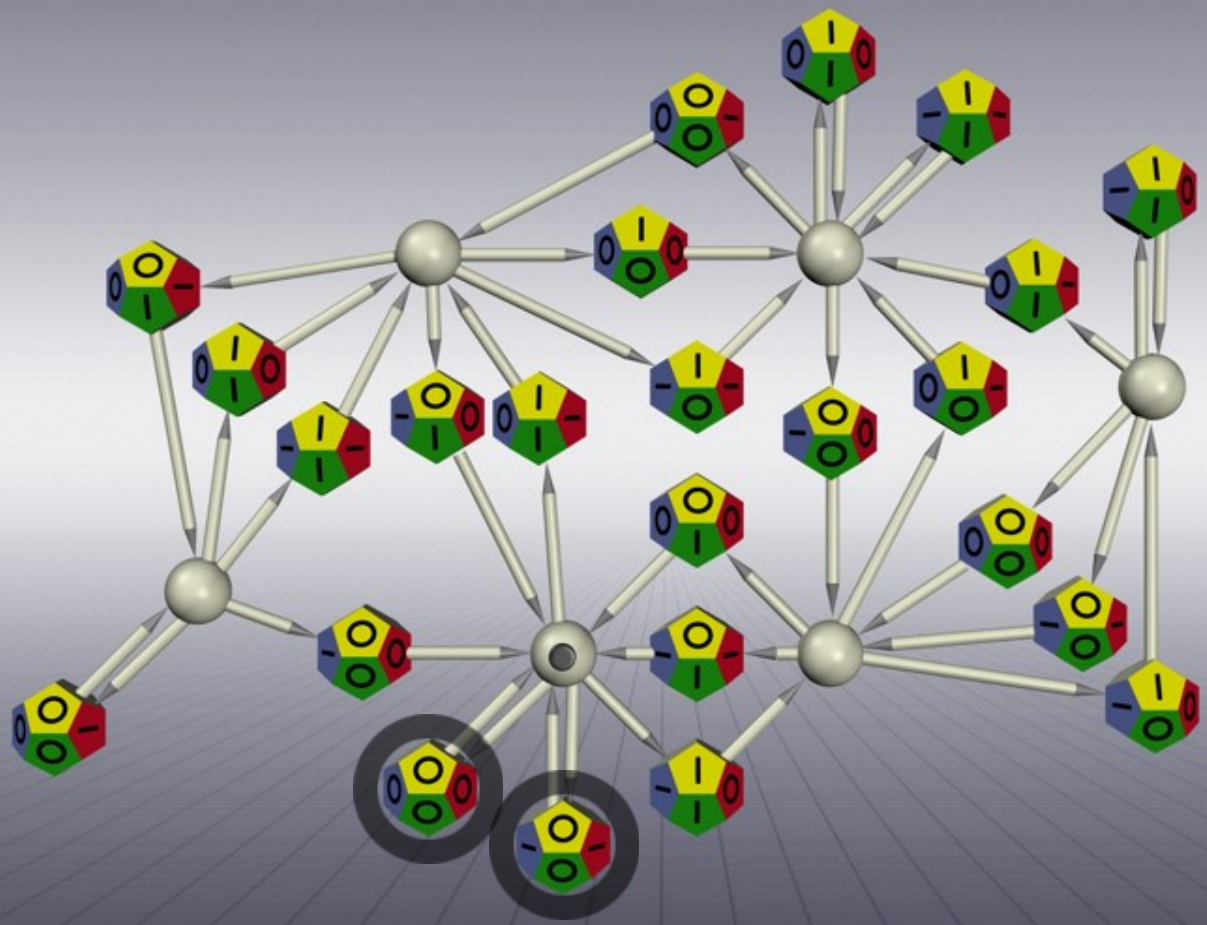

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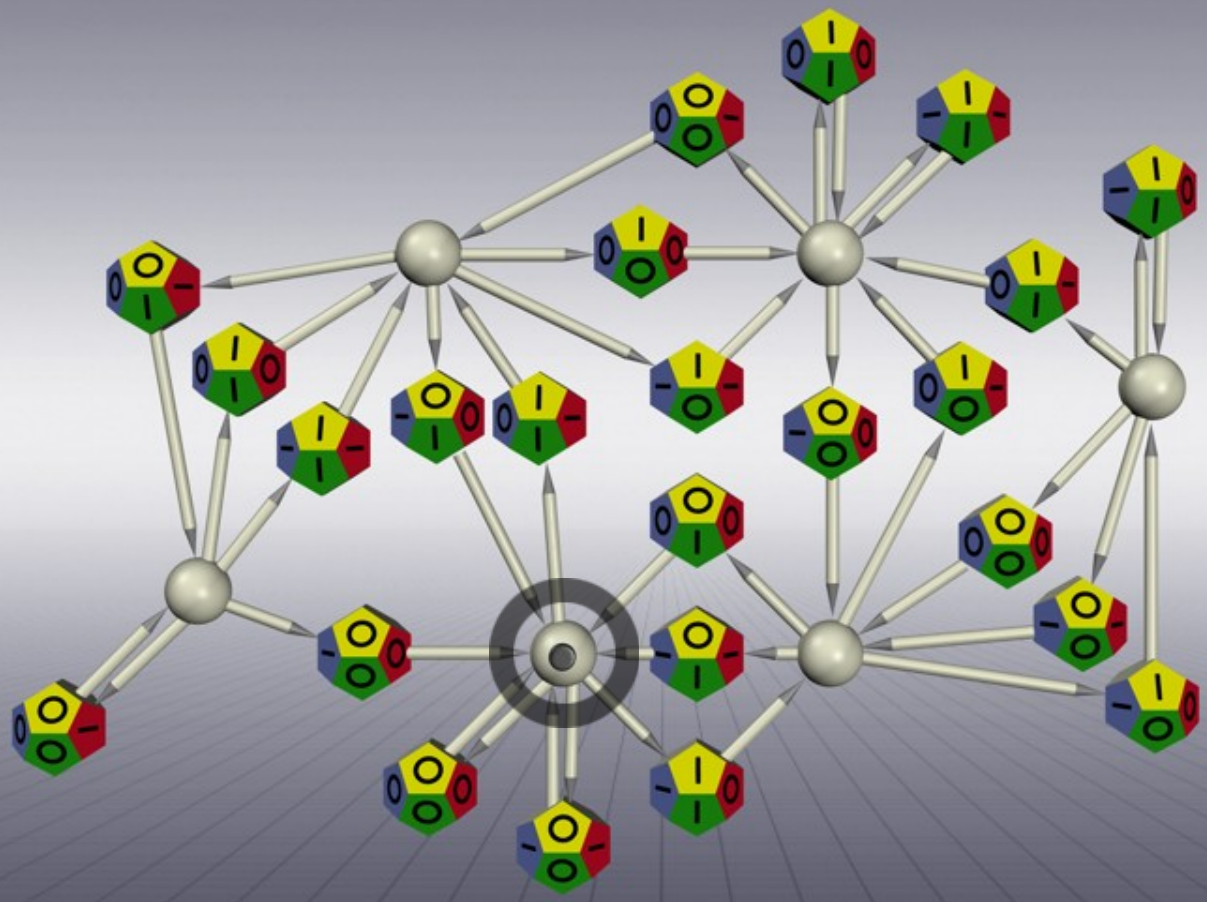

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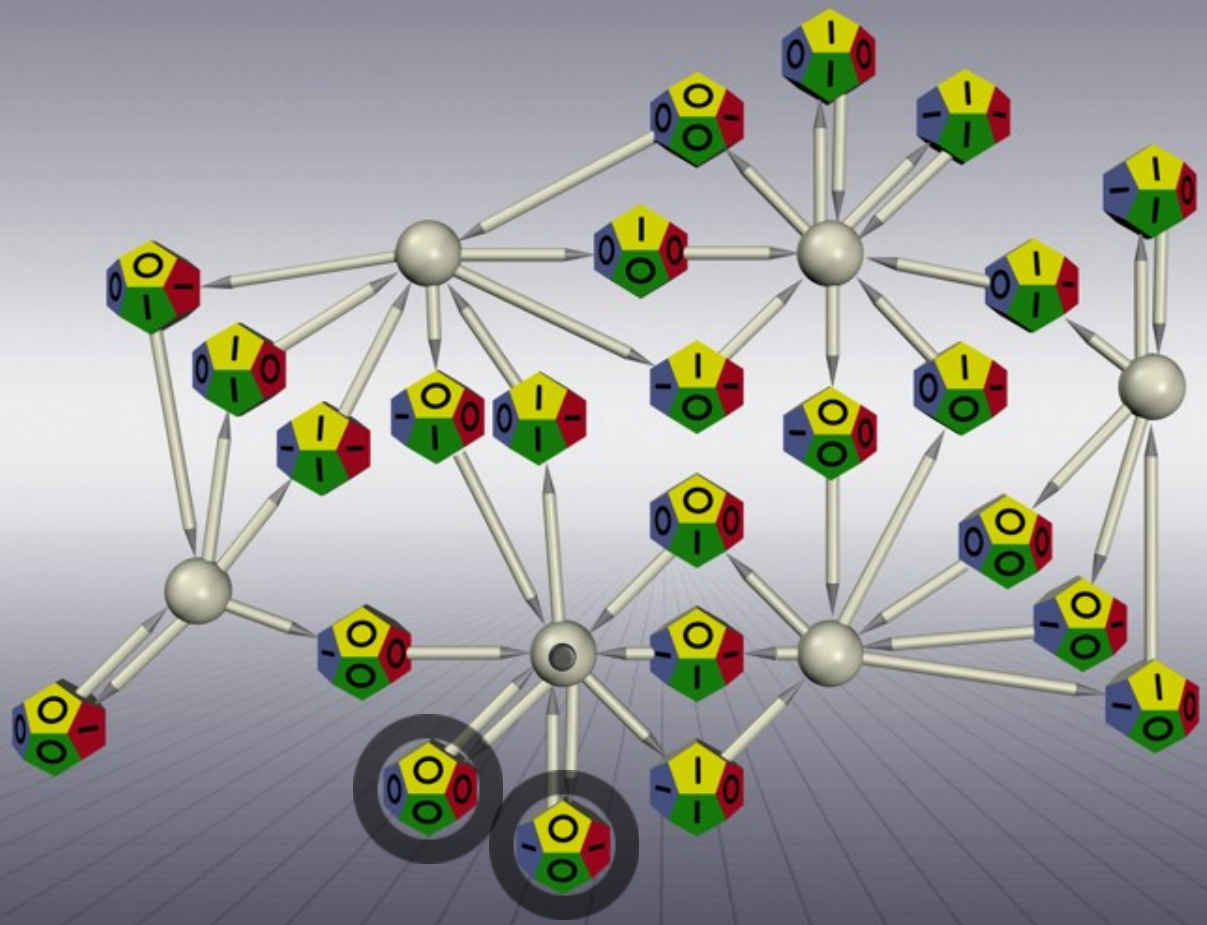

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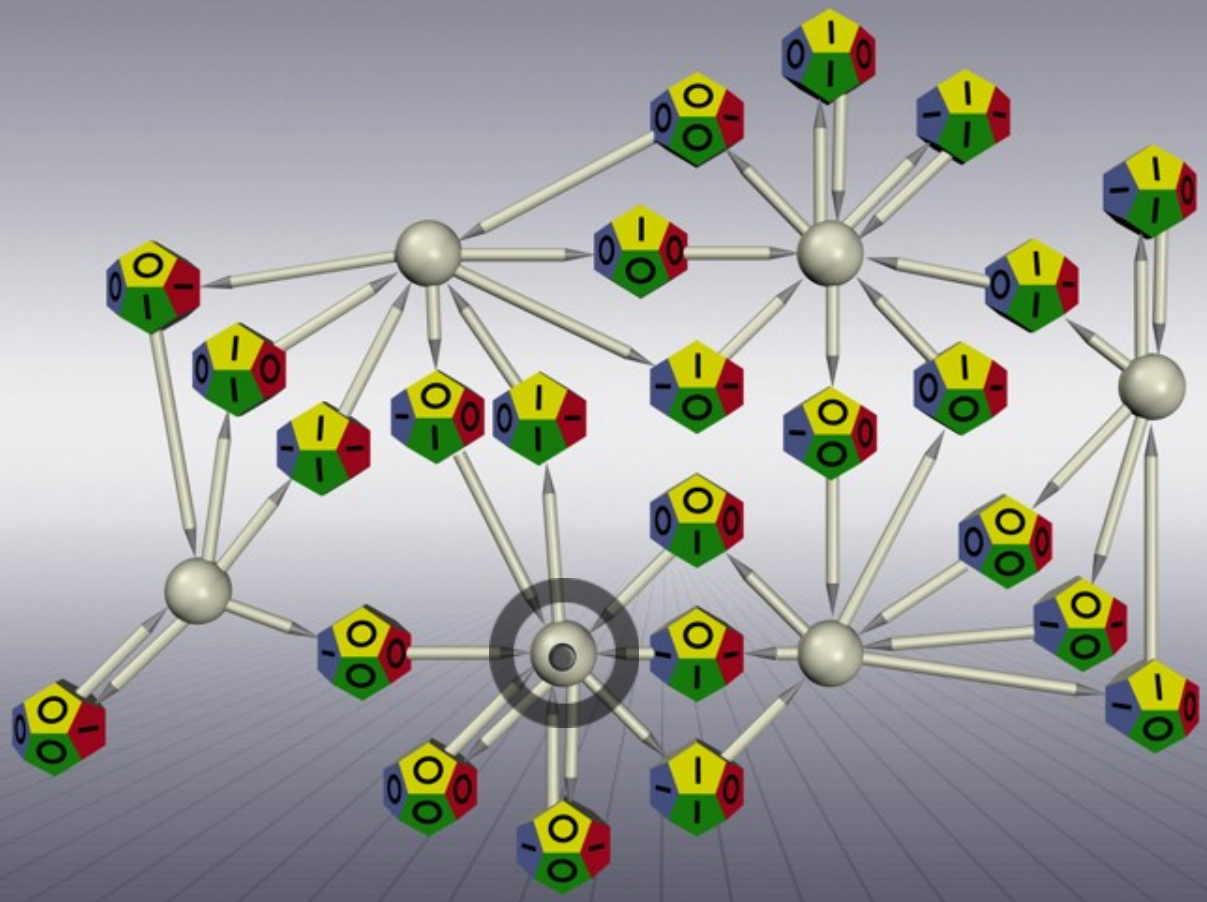

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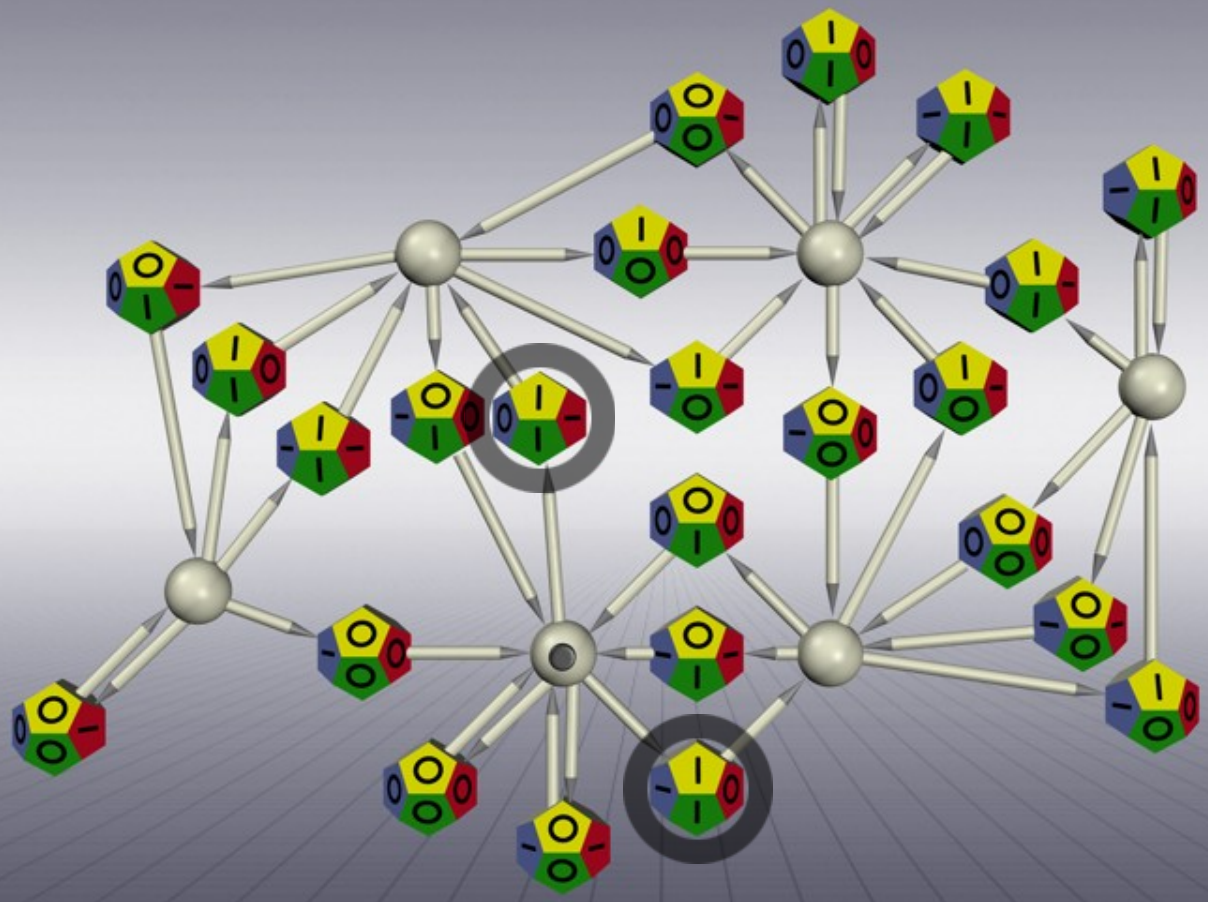

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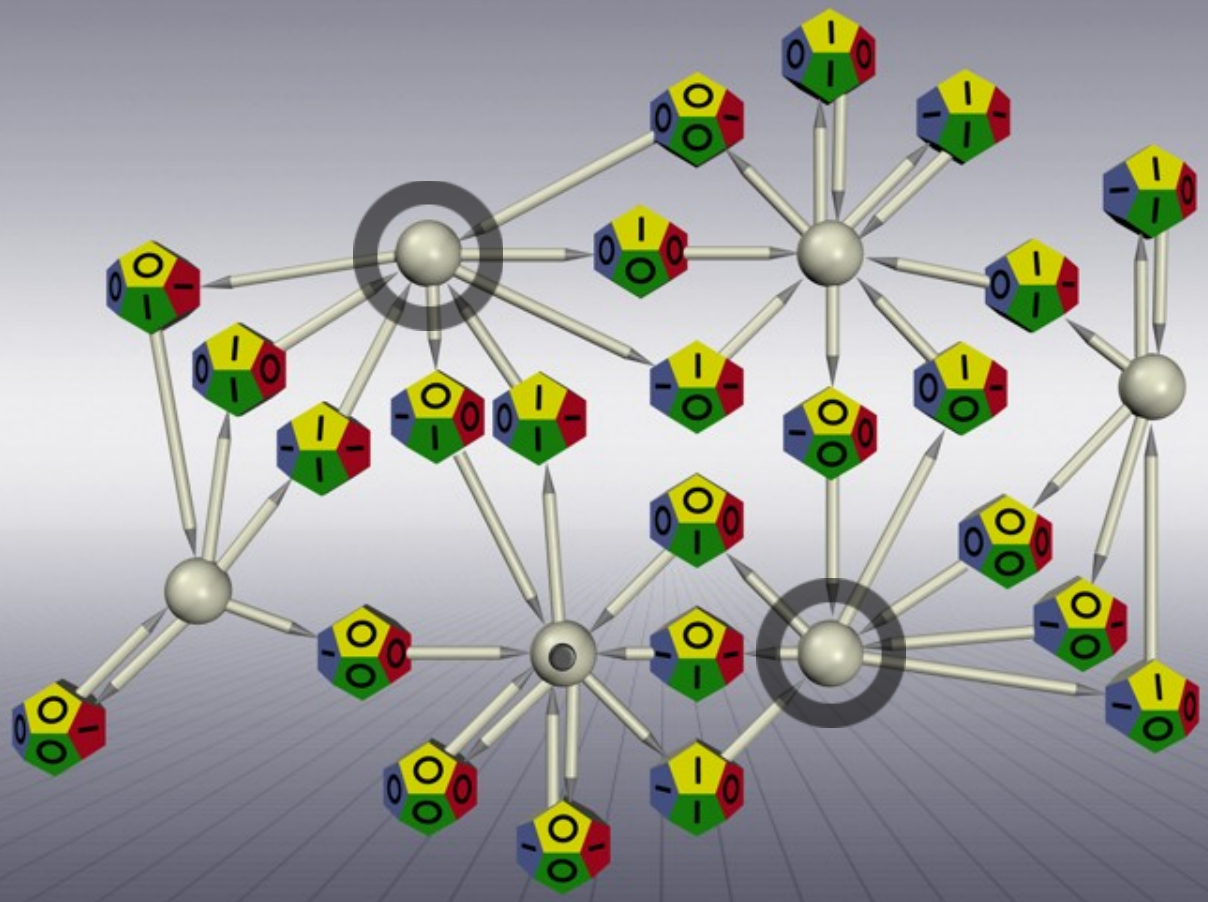

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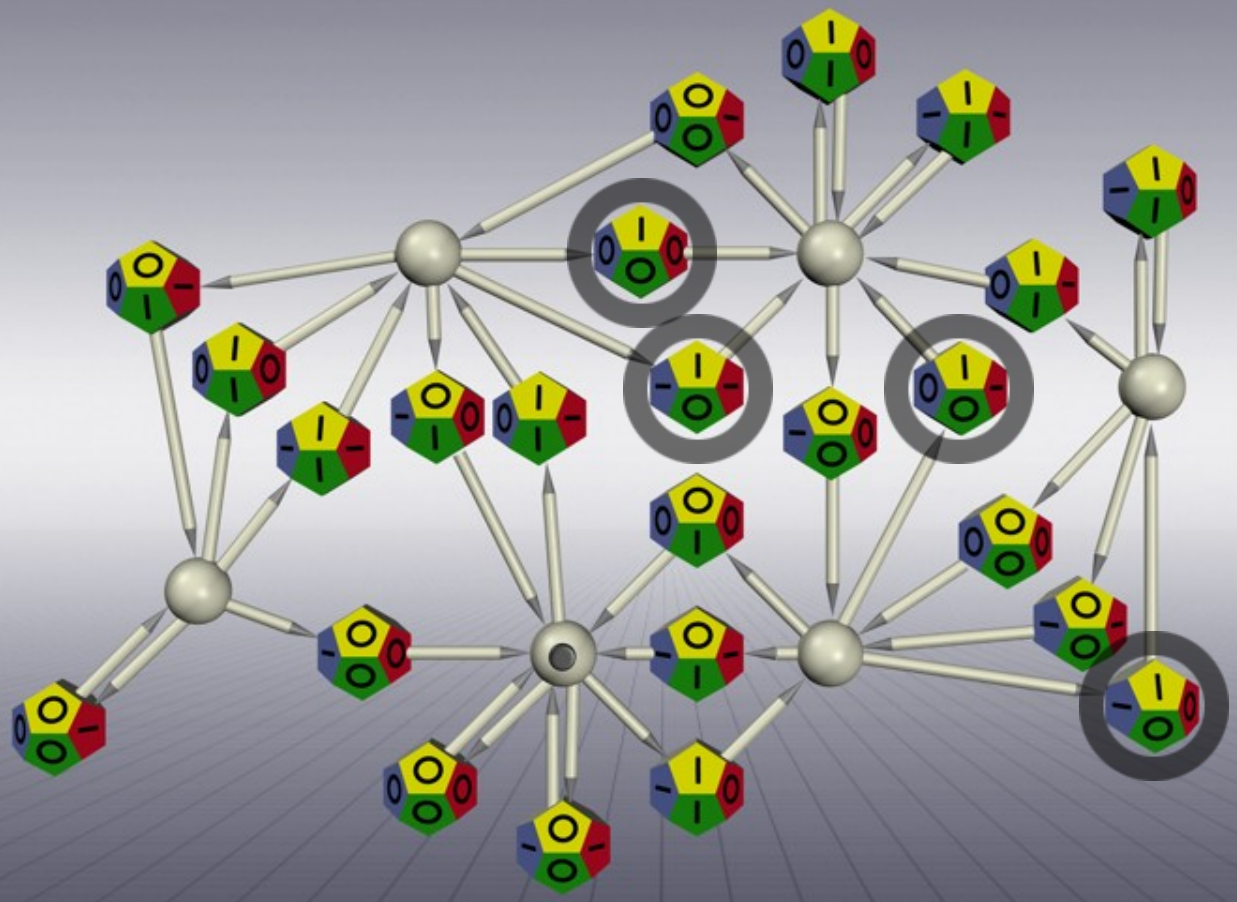

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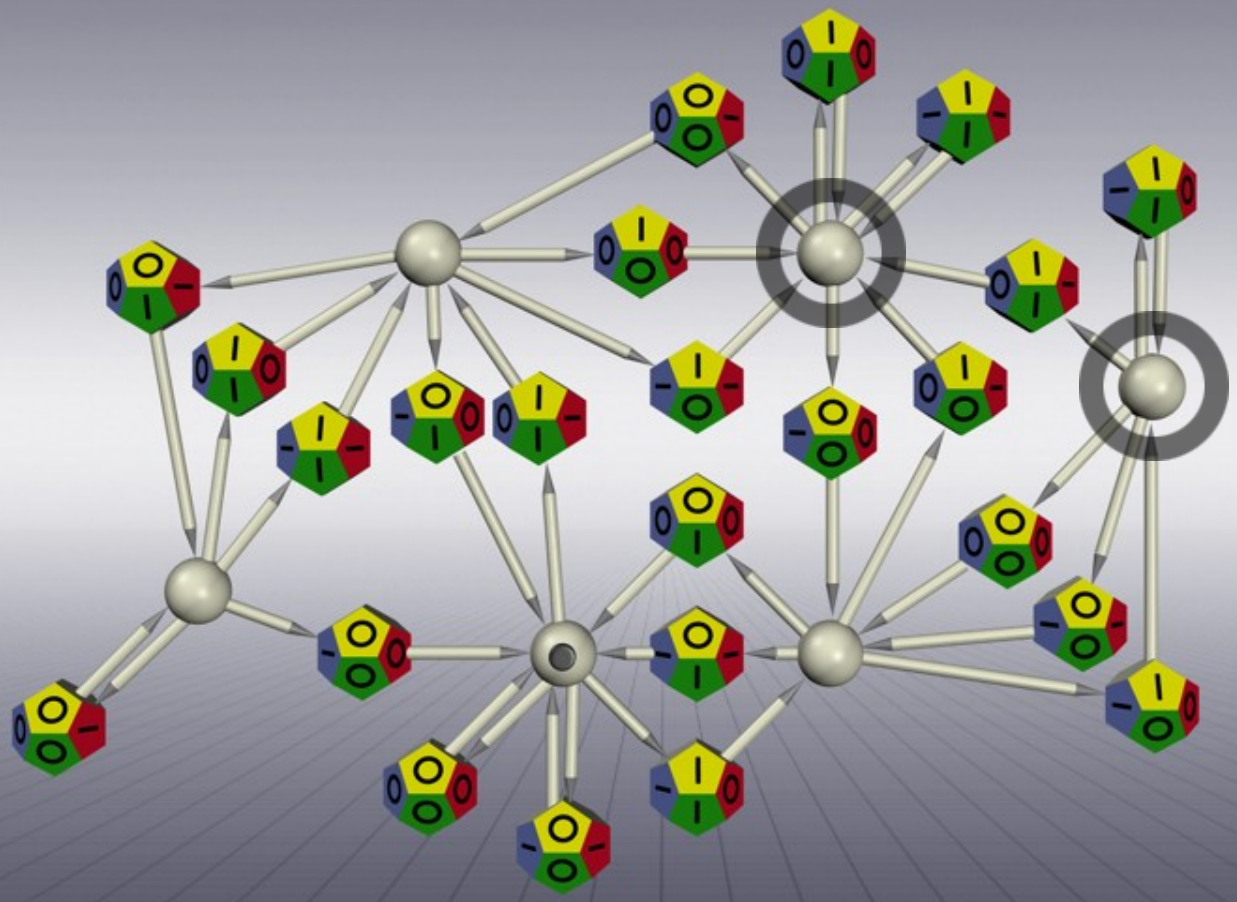

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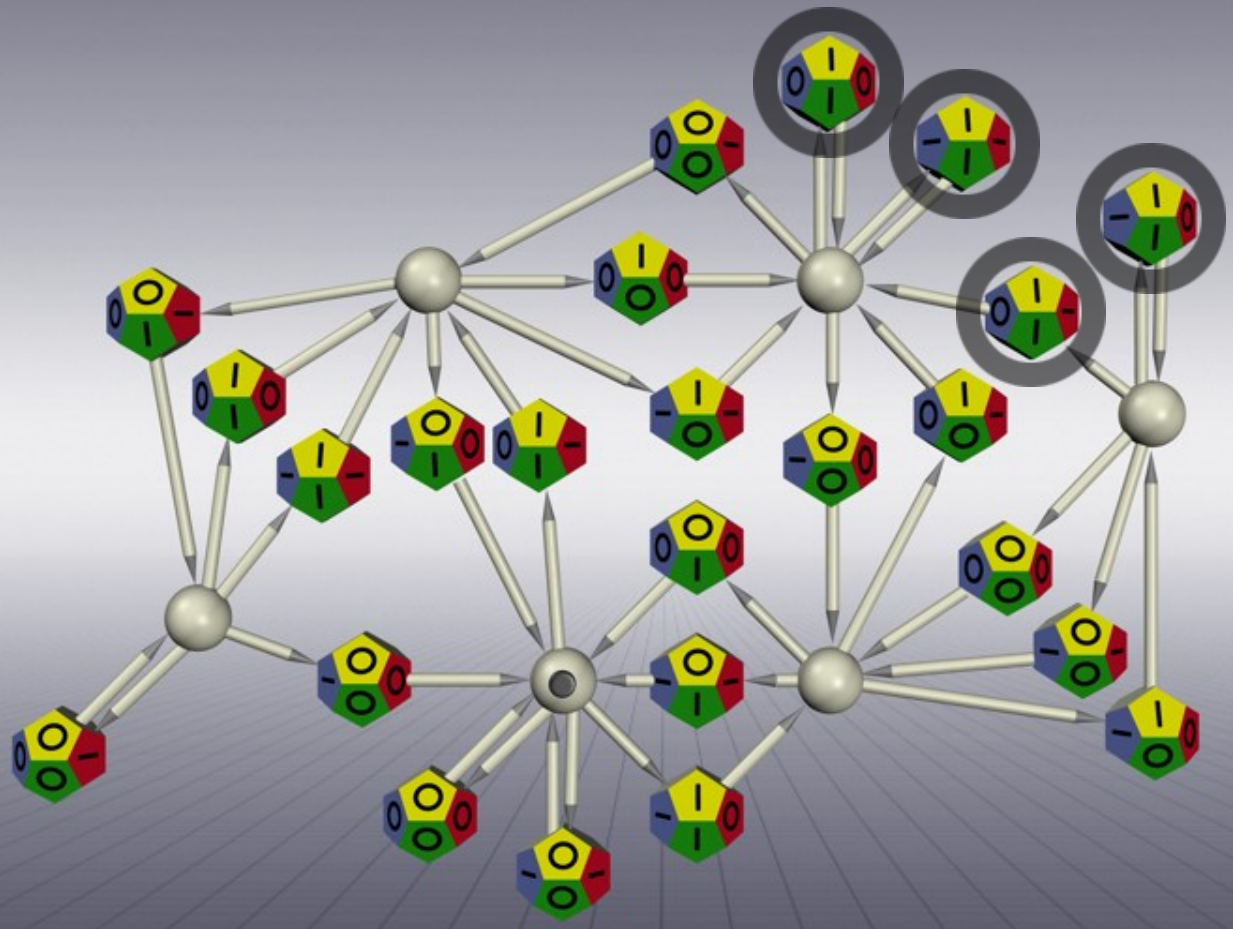

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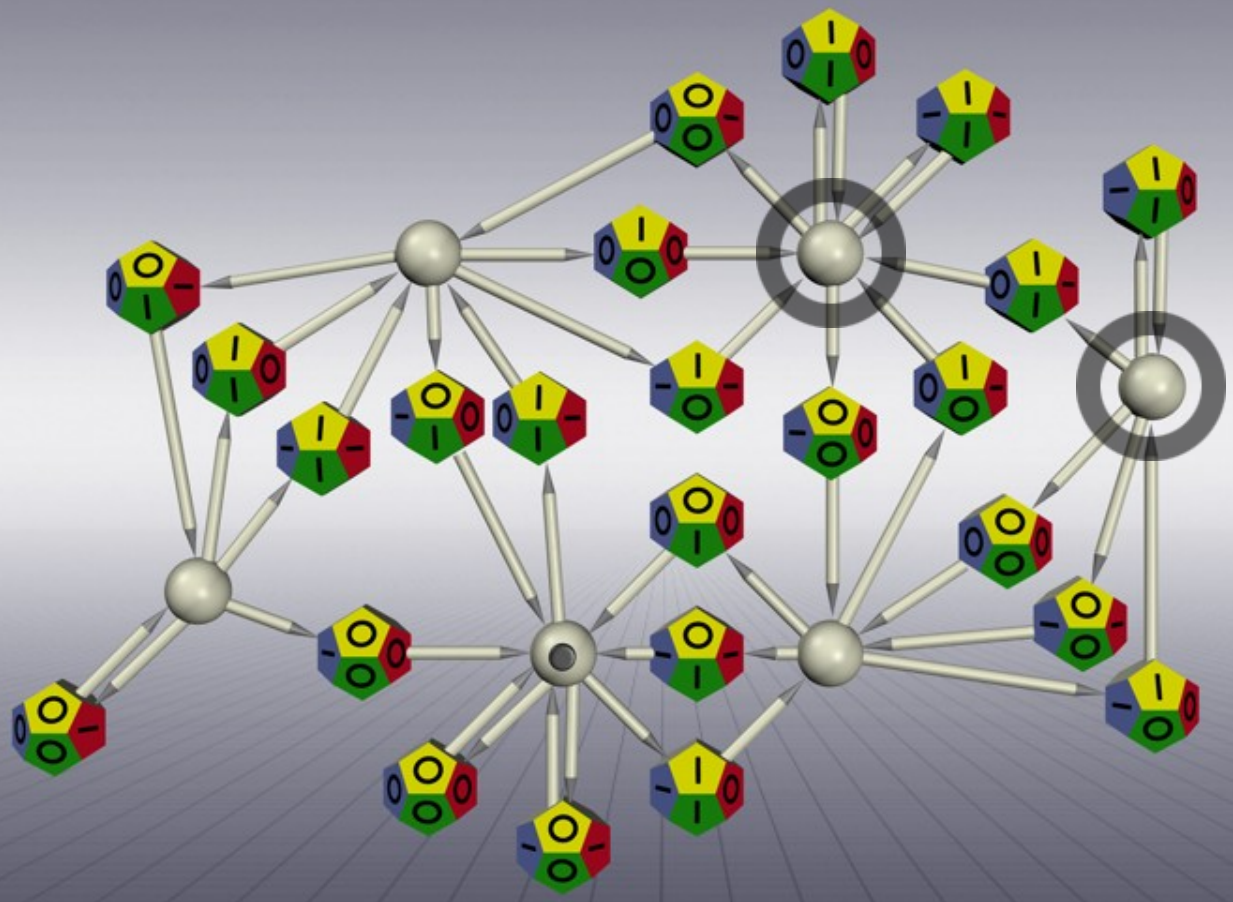

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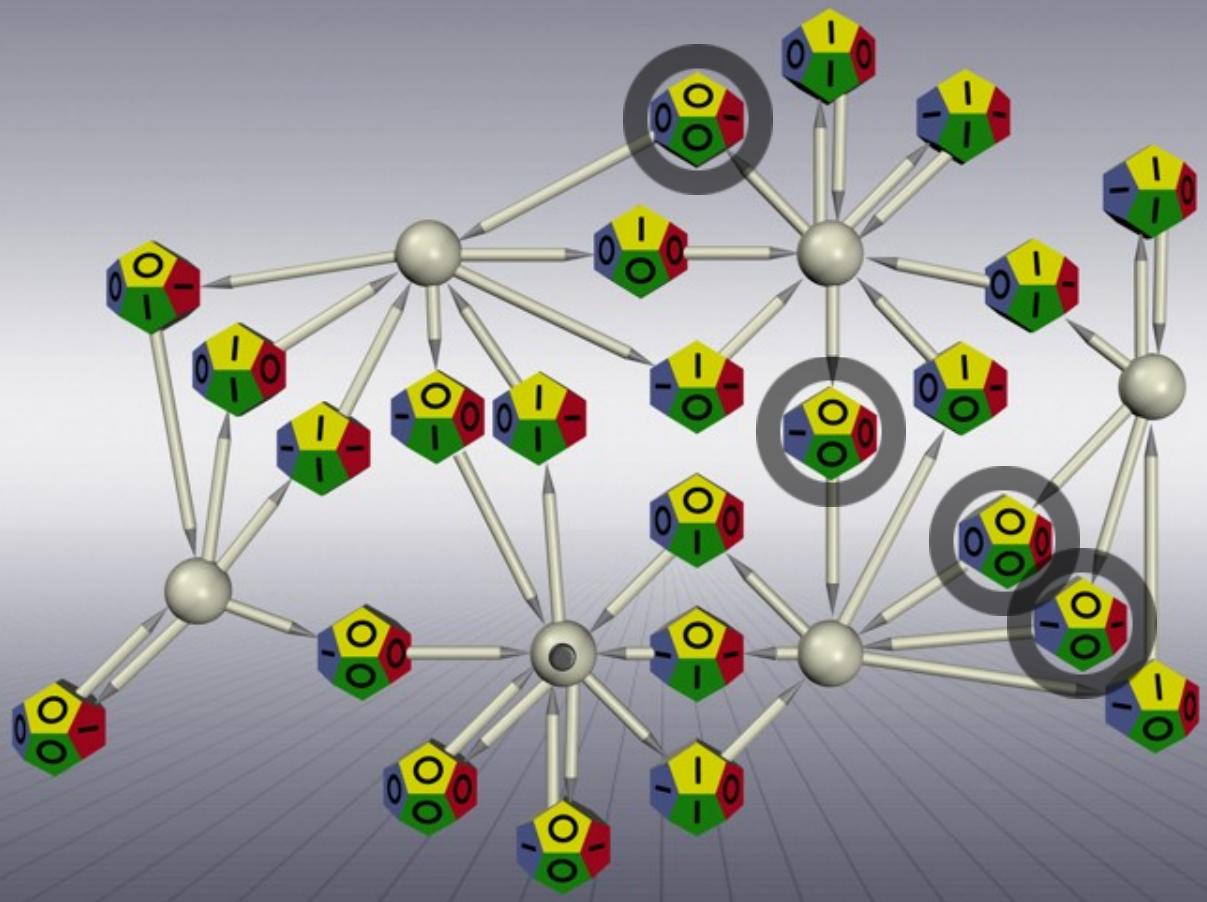

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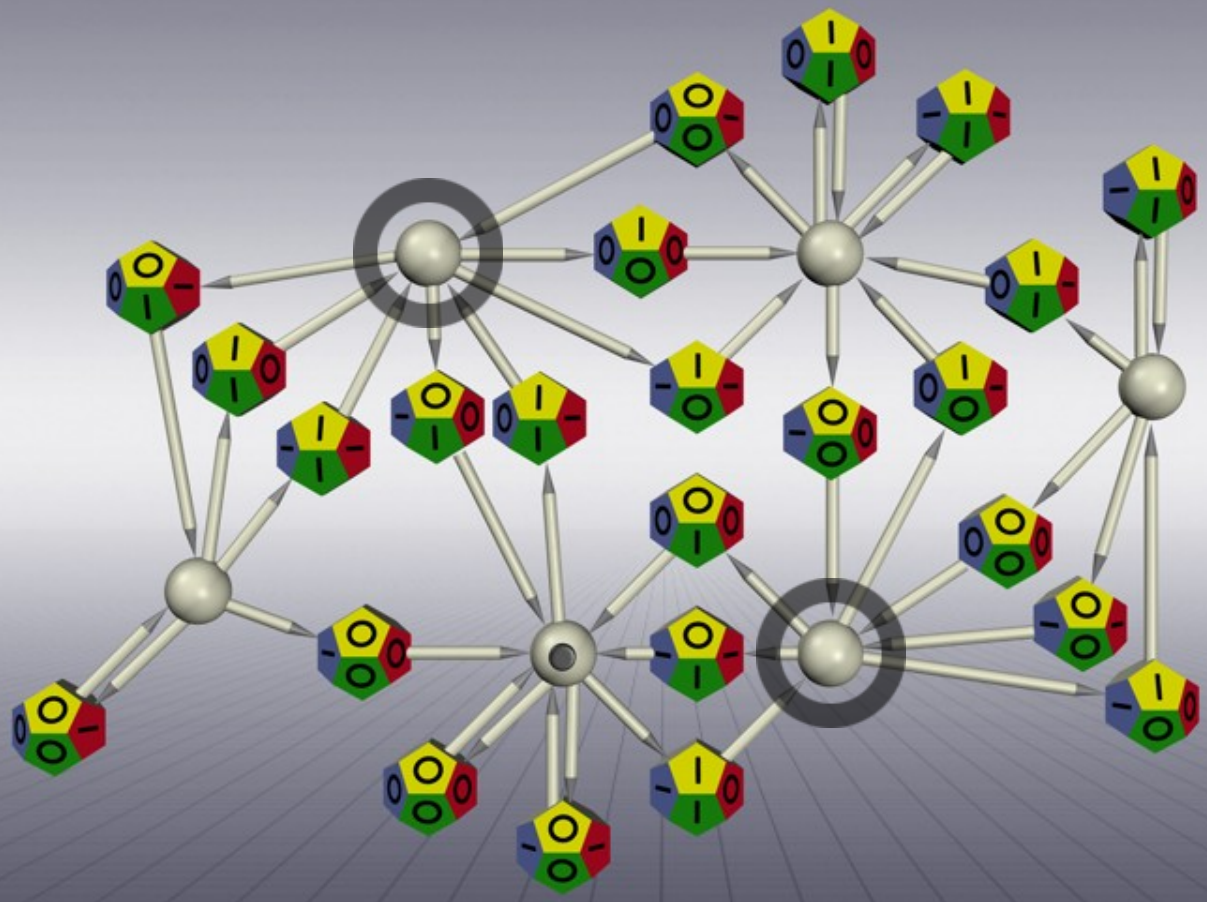

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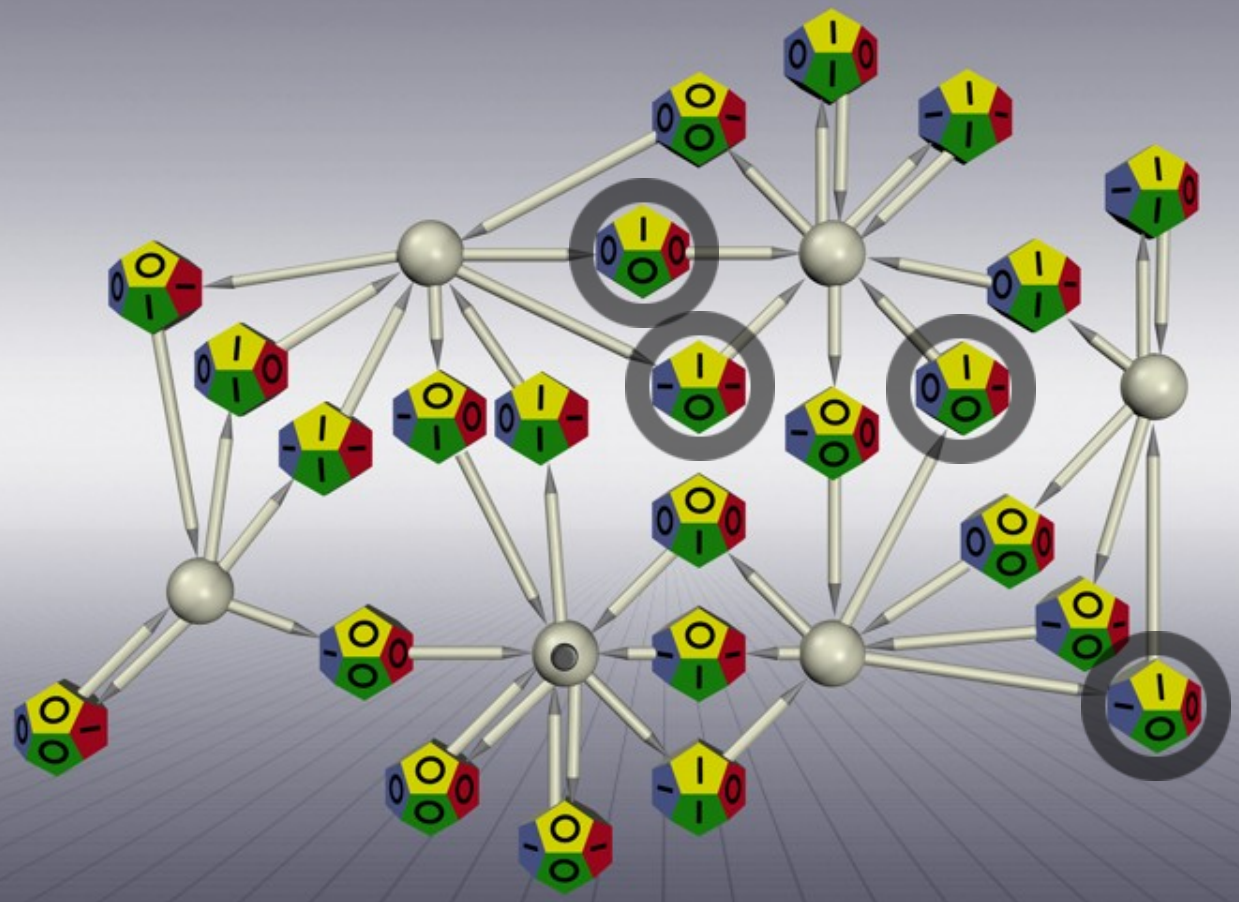

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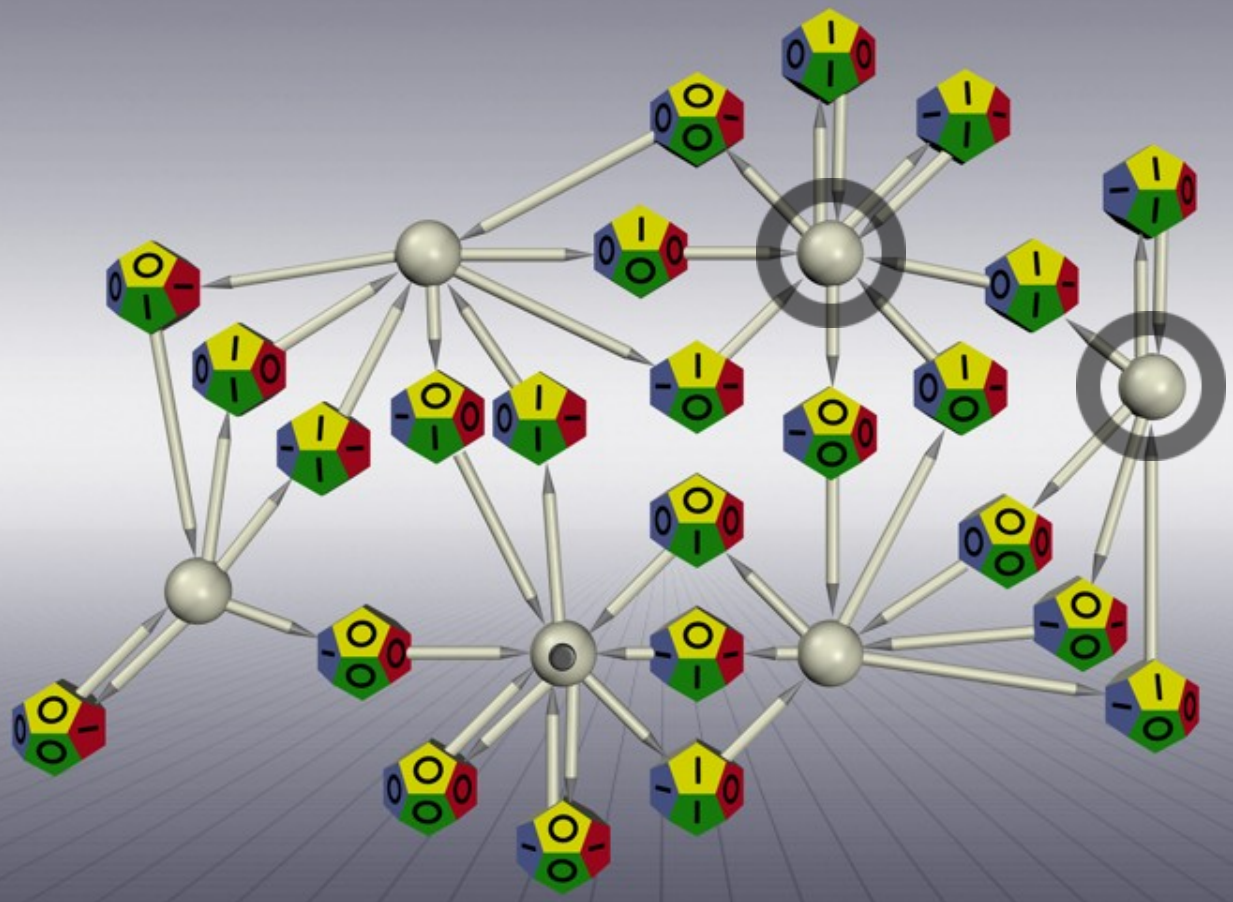

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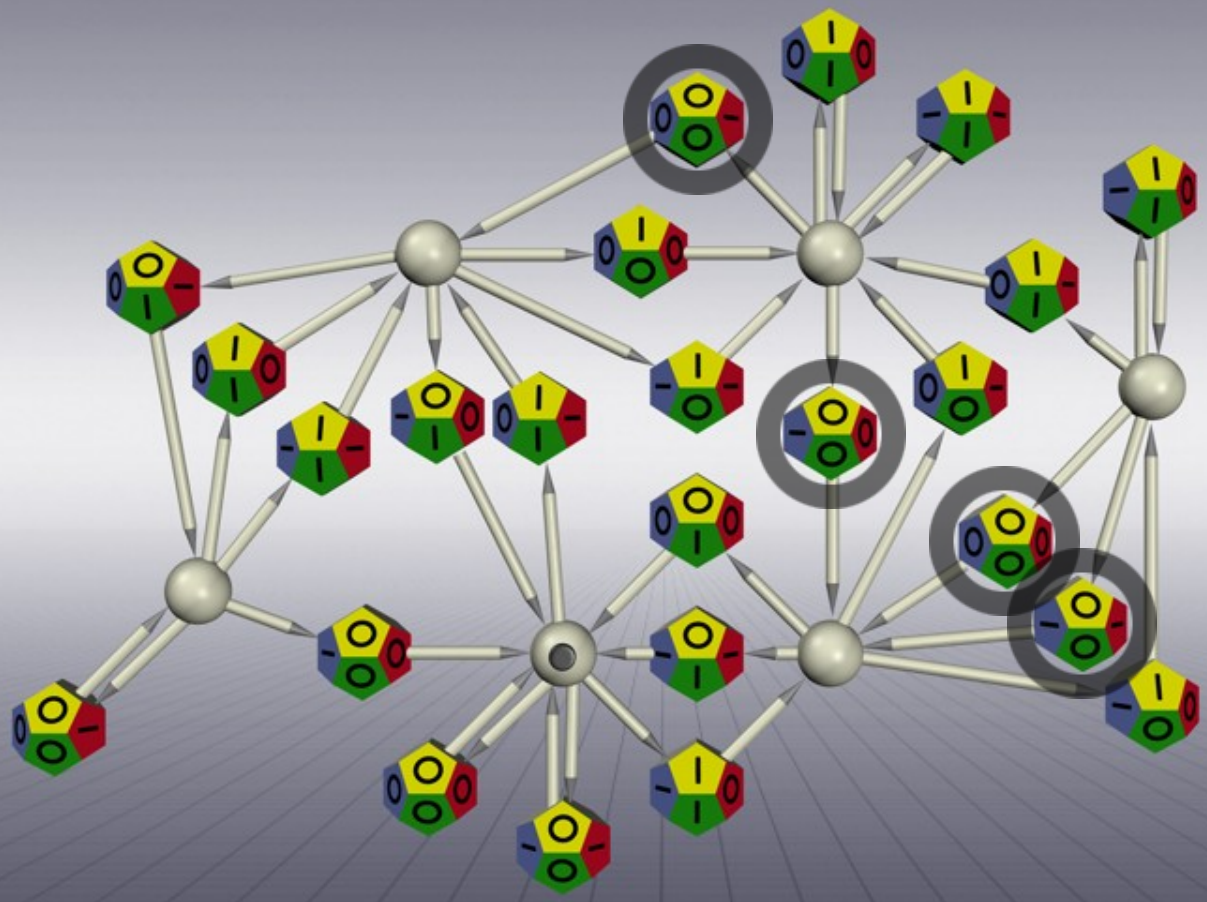

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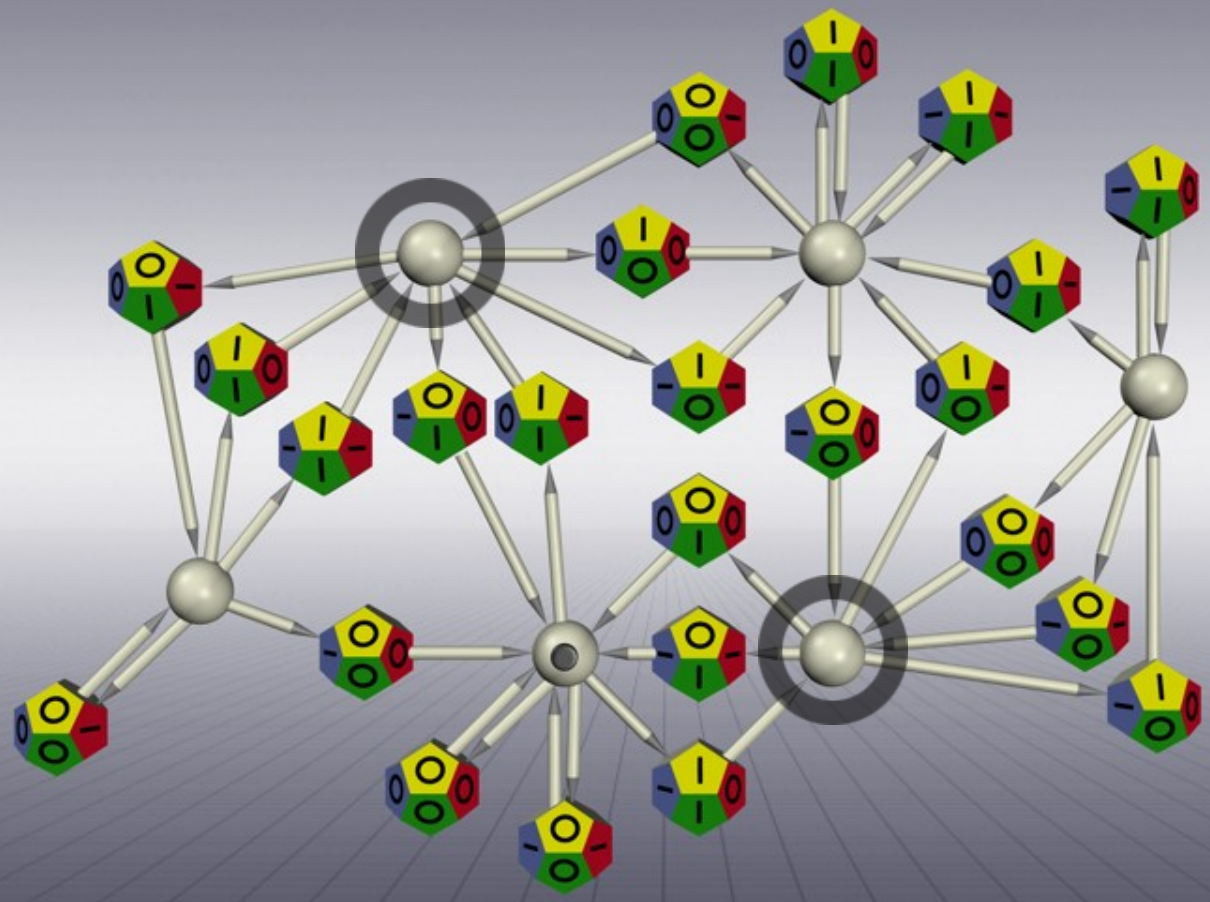

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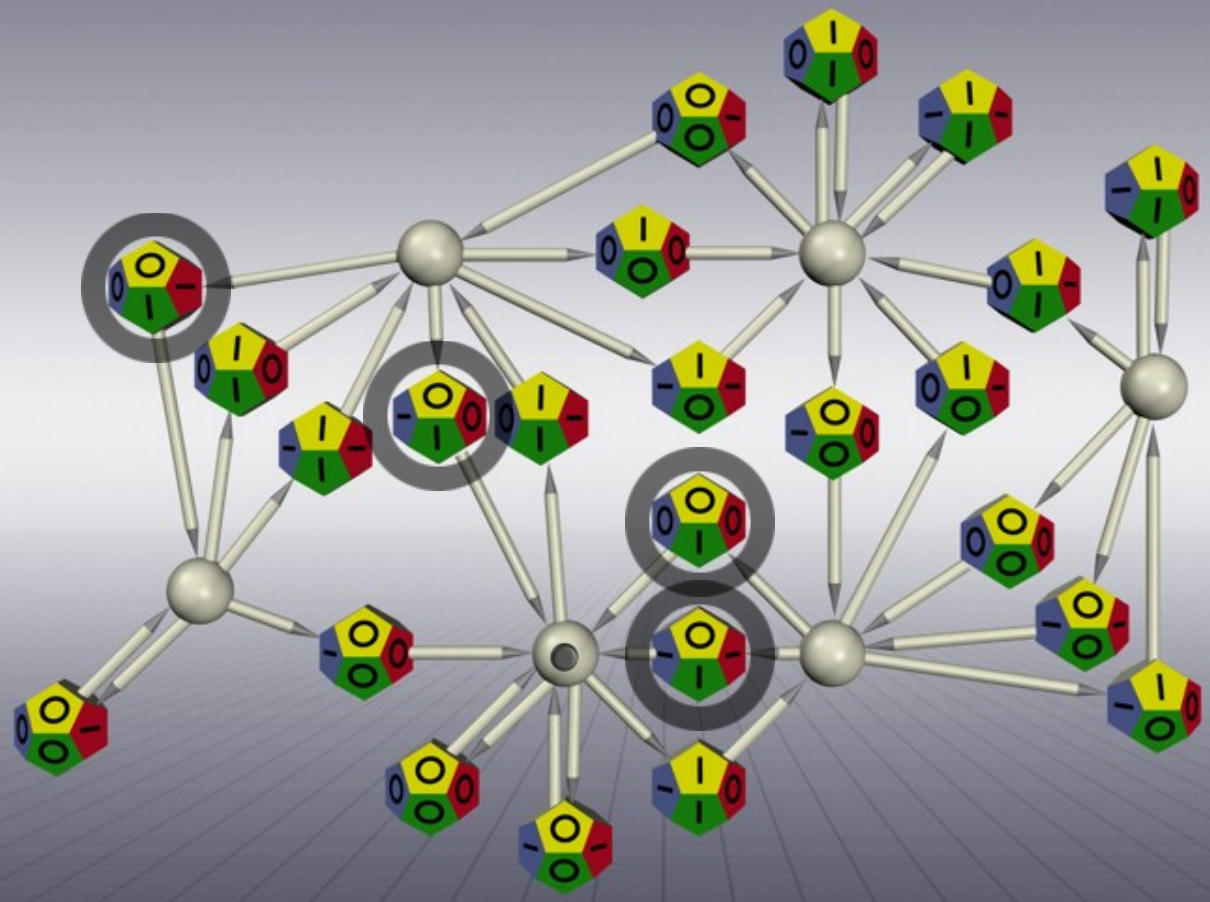

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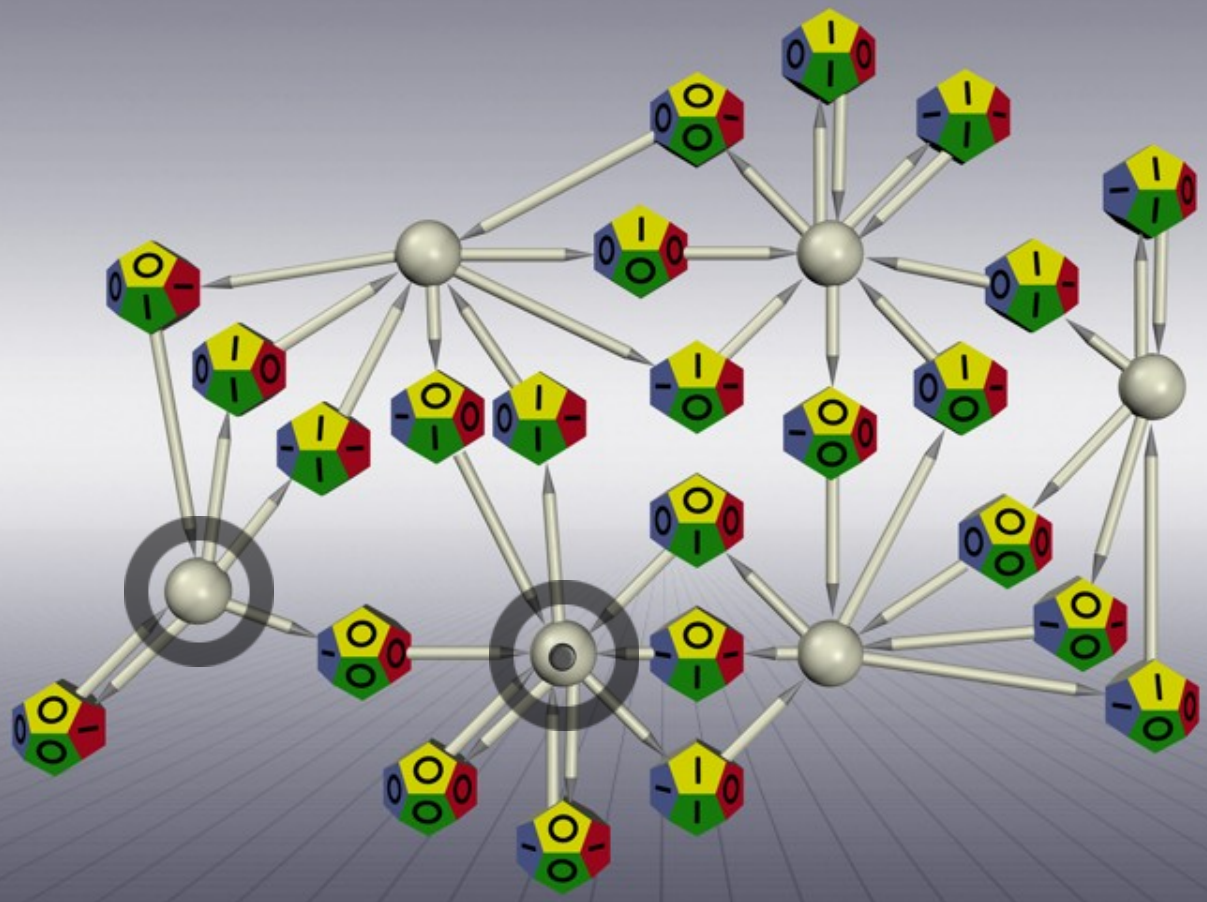

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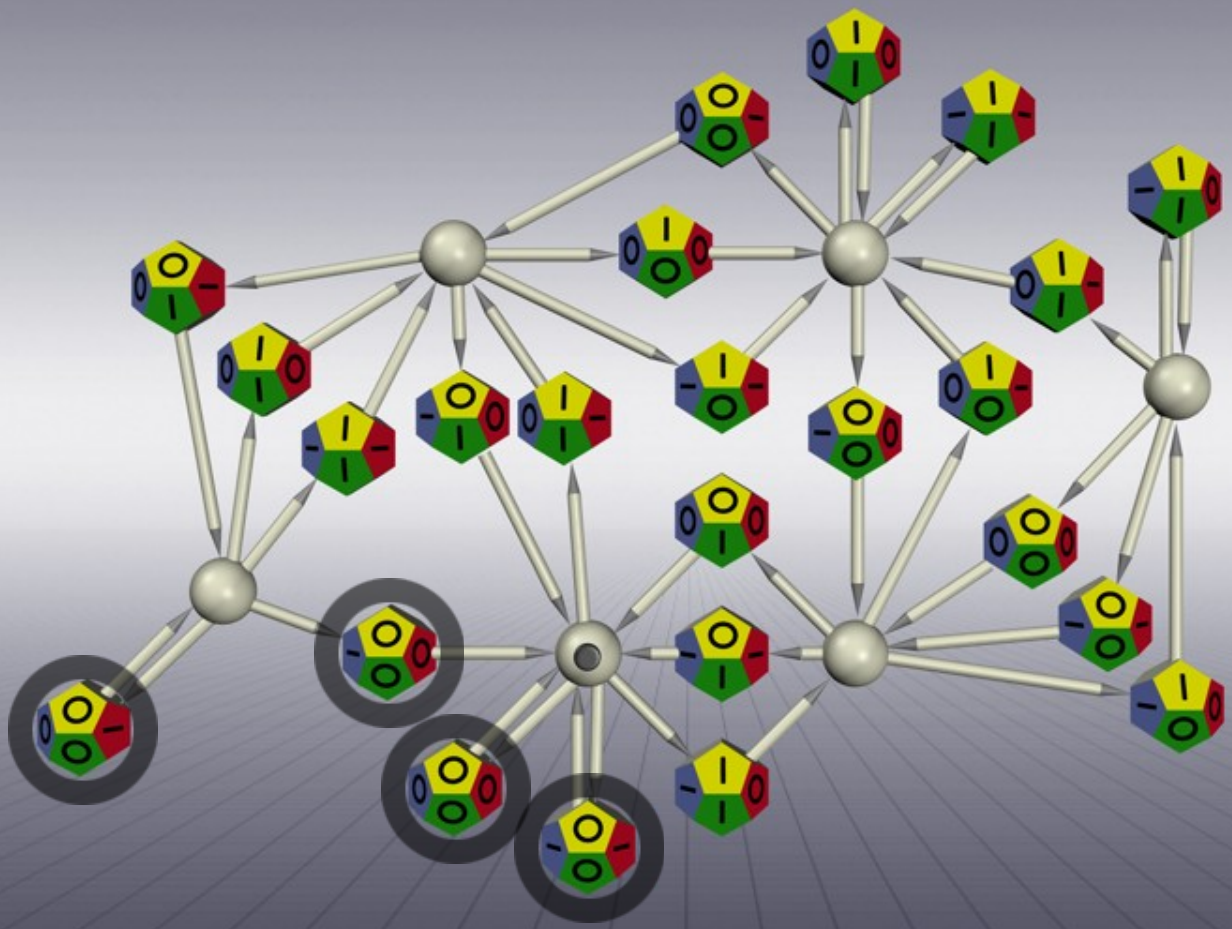

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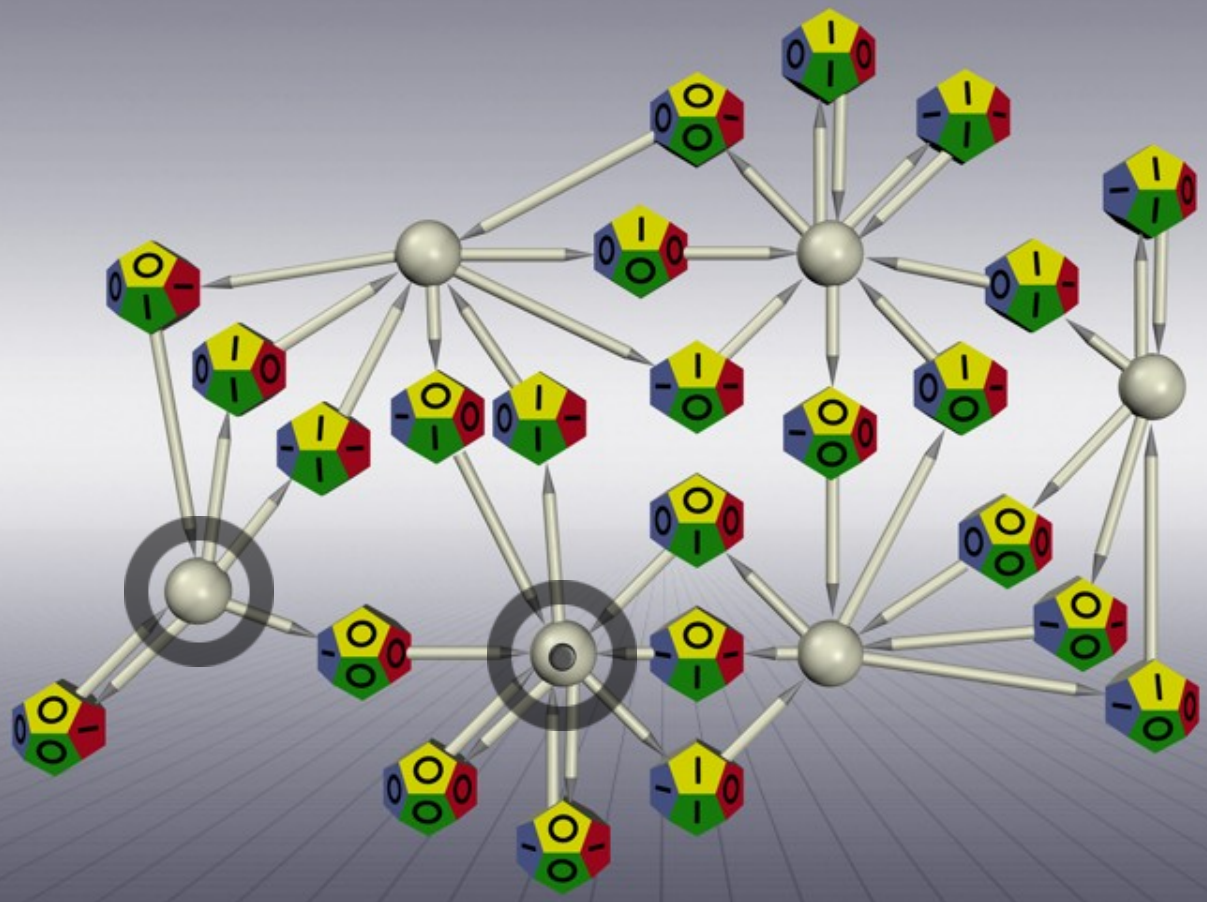

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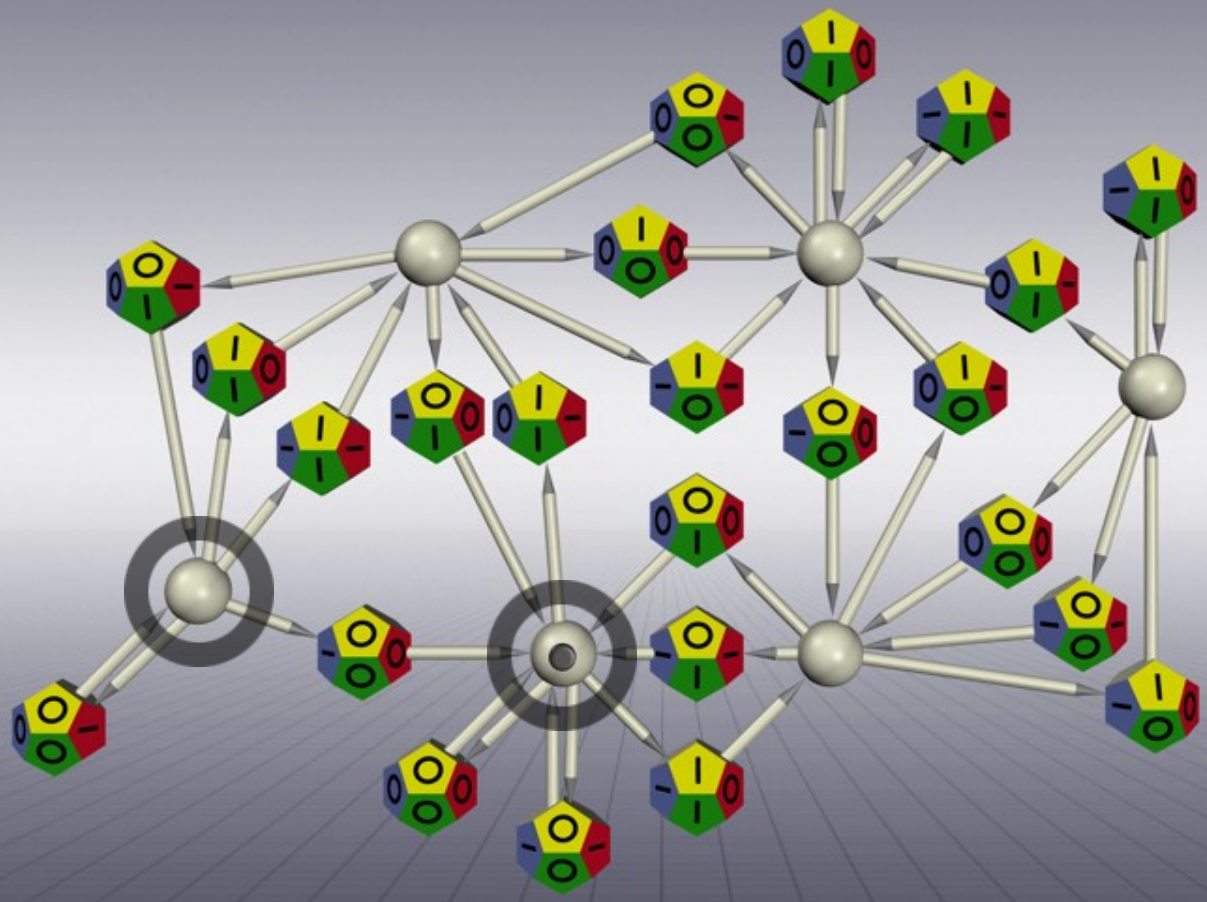

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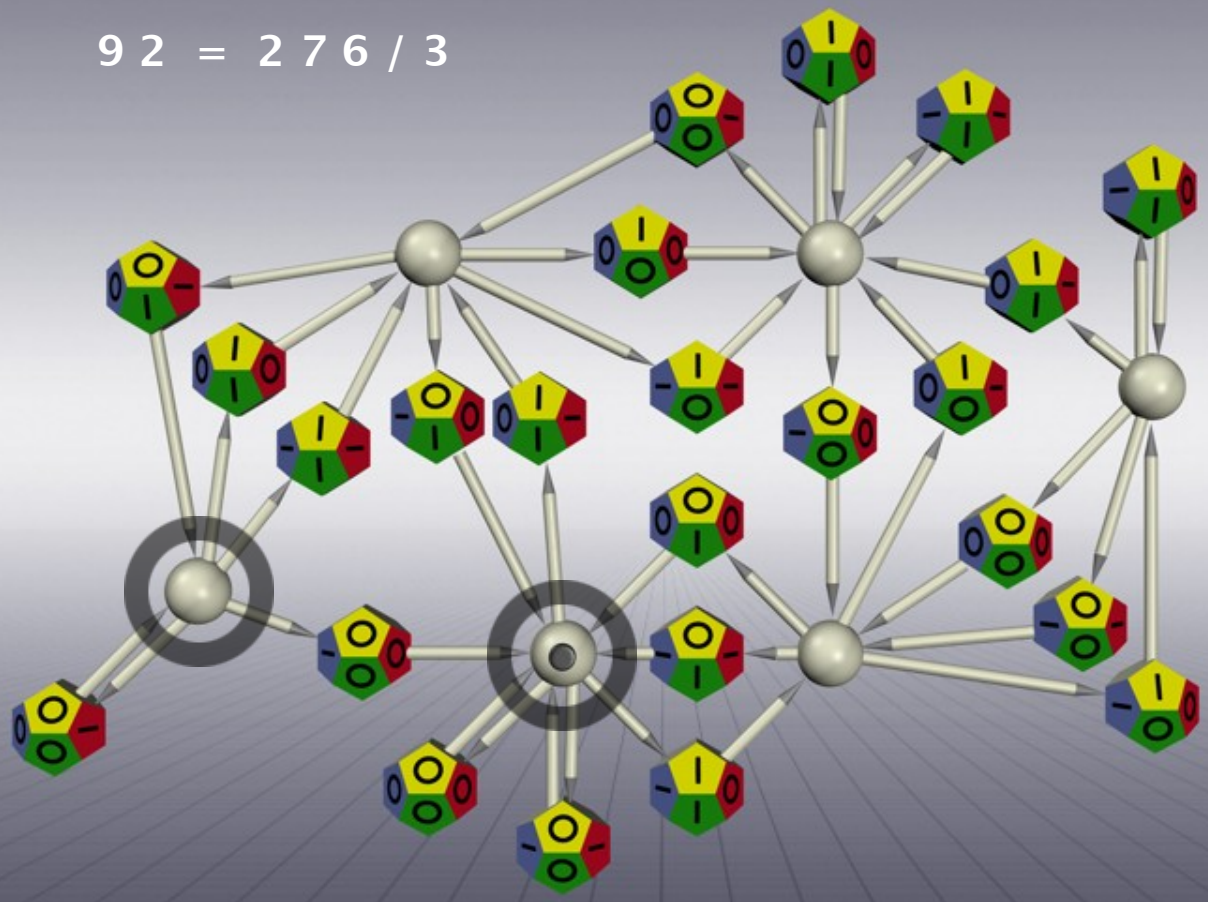

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