Tuples and lists

- tuples
- lists
- mutability
- list comprehension
- for-if, for-for
- list()
- any(), all()
- enumerate(), zip()

Tuples

$(\text{value}_0, \text{value}_1, \ldots, \text{value}_{k-1})$

- Tuples can contain a sequence of zero or more elements, enclosed by ”(” and ”)”
- Tuples are immutable
- Tuple of length 0: ()
- Tuple of length 1: (value,)

  Note the comma to make a tuple of length one distinctive from an expression in parenthesis
- In many contexts a tuple with ≥ 1 elements can be written without parenthesis
- Accessors to lists also apply to tuples, slices, ...

Python shell

```
> (1, 2, 3)
| (1, 2, 3)
> ()
| ()
> (42)
| 42
> (42,)
| (42,)
> 1, 2
| (1, 2)
> 42,
| (42,)
> x = (3, 7)
> x
| (3, 7)
> x = 4, 6
> x
| (4, 6)
> x[1] = 42
| TypeError: 'tuple' object does
  not support item assignment
```

Question – What value is `((42,))` ?

a) `42`

b) `(42)`

c) `(42,)`

d) `((42,),)`

e) Don’t know

Warning: Unintended tuples

Python shell

```
>x = 7,      # x = (7,)
>y = 5,      # y = (5,)
>x + y
 (7, 5)
```

Question – What is `x` ?

```
x = [1, [2, 3], (4, 5)]
x[2][0] = 42
```

a) `[1, [42, 3], (4, 5)]`

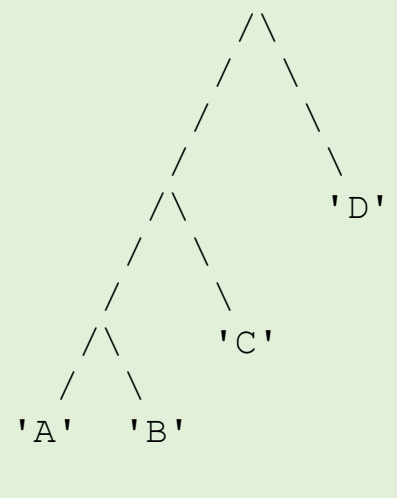
b) `[1, [2, 3], (42, 5)]`

c) `[1, [2, 3], 42]`

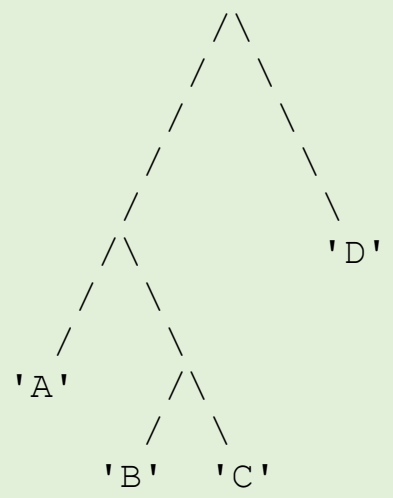
d) TypeError

e) Don’t know

Question – What tree is `('A',(('B','C'),'D'))` ?



a)



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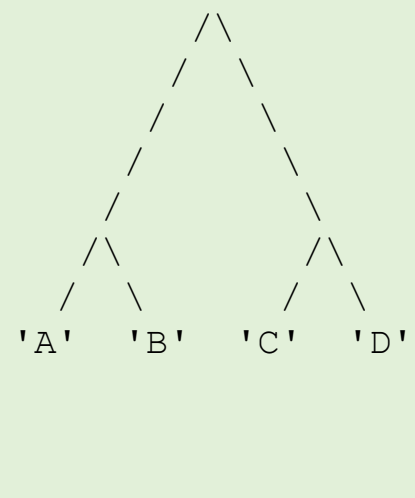

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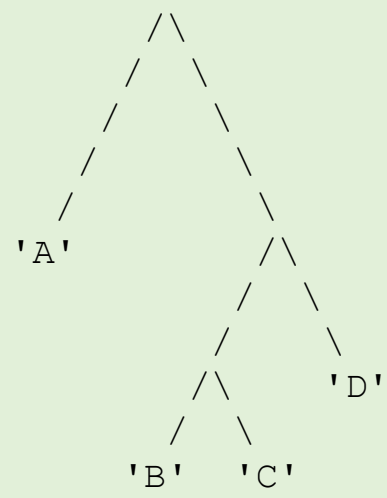
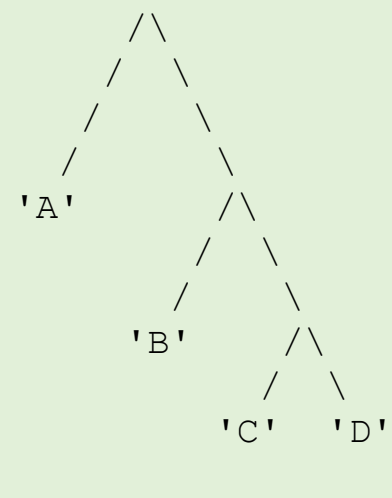


d)



e)

f) Don’t know

Tuple assignment


```
Python shell
> point = (10, 25)
> x, y = point
> x
| 10
> y
| 25
```

- Parallel assignments

```
x, y, z = a, b, c
```

is a shorthand for a tuple assignment (right side is a single tuple)

```
(x, y, z) = (a, b, c)
```

- First the right-hand side is evaluated completely, and then the individual values of the tuple are assigned to `x`, `y`, `z` left-to-right (length must be equal on both sides)

Nested tuple/lists assignments

- Let hand side can be nested (great for unpacking data)

```
(x, (y, (a[0], w)), a[1])
   = 1, (2, (3, 4)), 5
```

- [...] and (...) on left side matches both lists and tuples of equal length (but likely you would like to be consistent with type of parenthesis)

Python shell

```
> two_points = [(10, 25), (30, 40)]
> (x1, y1, x2, y2) = two_points
| ValueError: not enough values to
  unpack (expected 4, got 2)
> ((x1, y1), (x2, y2)) = two_points
> a = [None, None]
> v = ((2, (3, 4)), 5)
> ((y, (a[0], w)), a[1]) = v
> a
| [3, 5]
> [x, y, z] = (3, 5, 7)
> (x, y, z) = [3, 5, 7]
> [x, (y, z), w] = (1, [2, 3], 4)
> [x, (y, z), w] = (1, [2, (5, 6)], 4)
> z
| (5, 6)
```

Unpacking a sequence with one element

Python shell

```
> x = [42]  # simple assignment
> x
| [42]
> x, = [42]  # unpacking, implicit parenthesis
> x
| 42
> (x,) = [42]  # unpacking
> x
| 42
> x, = [1, 2, 3]
| ValueError: too many values to unpack (expected 1)
```

Tuples vs lists: `a += b`

- Lists
  Extends existing list, i.e. same as `a.extend(b)`

- Tuples
  Must create a new tuple `a + b` and assign to `a` (since tuples are immutable)

Python shell

```
> (1, 2) + (3, 4)
| (1, 2, 3, 4)
> x = [1, 2]
> y = x
> y += [3, 4]
> y
| [1, 2, 3, 4]
> x
| [1, 2, 3, 4]

> x = (1, 2)
> y = x
> y += (3, 4)
> y
| (1, 2, 3, 4)
> x
| (1, 2)
```

More on `+=` on lists

- Since `a += b` is the same as `a.extend(b)` we can also do

Python shell

```
> x = [1, 2, 3]
> x += [4, 5, 6]
> x += (7, 8, 9)
> x += range(10, 13)   # 10, 11, 12
> x += 'abc'           # 'a', 'b', 'c'
> print(x)
| [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 'a', 'b', 'c']
> x = [1, 2, 3] + (4, 5, 6)
| TypeError: can only concatenate list (not "tuple") to list
```

- For tuples `+=` only accepts tuples

*variable assignment

- For a tuple of variable length a single **variable name* on the left side will be assigned a *list* of the remaining elements not matched by variables preceding/following *
- *Example*

```
a, *b, c = t
```

  is equivalent to

```
a = t[0]
b = t[1:-1]
c = t[-1]
```

- There can be a single * in a left-hand-side tuple (but one new * in each nested tuple)

Python shell

```
> (a, *b, c, d) = (1, 2, 3, 4, 5, 6)
> b
| [2, 3, 4]
> (a, *b, c, d) = (1, 2, 3)
> b
| []
> (a, *b, c, d) = (1, 2)
| ValueError: not enough values to
  unpack (expected at least 3, got 2)
> v = ((1,2,3),4,5,6,(7,8,9,10))
> ((a, *b), *c, (d, *e)) = v
> b
| [2, 3]
> c
| [4, 5, 6]
> e
| [8, 9, 10]
> head, *tail = [1, 2, 3, 4]
> head
| 1
> tail
| [2, 3, 4]
```

Question – What is `b` ?

```
(*a,(b,),c) = ((1,2),((3,4)),((5,)),(6))
```

a) `(1,2)`
b) `(3,4)`
c) `5`
d) `(5,)`
e) `(6)`
f) Don’t know

* in list and tuple construction

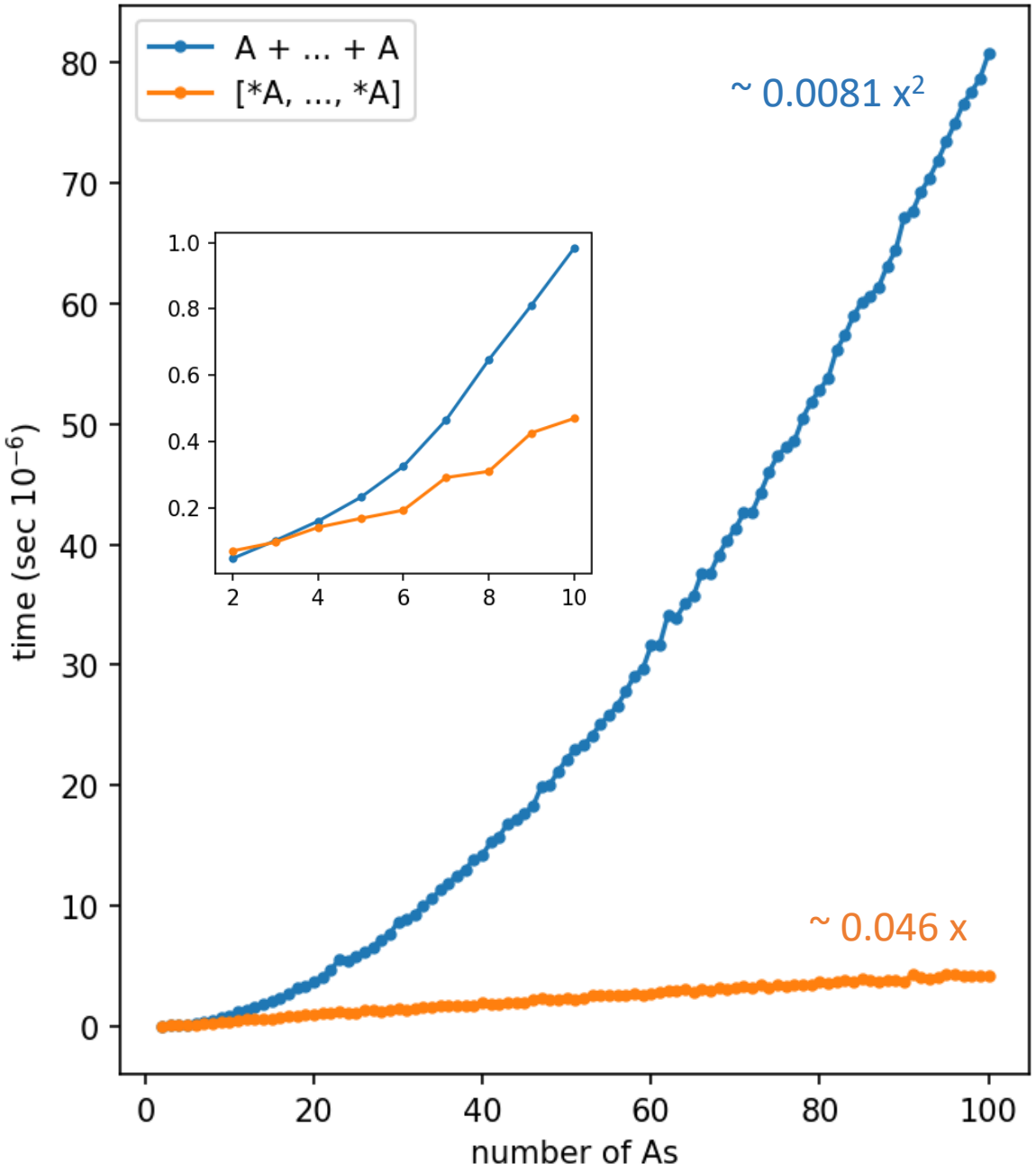
- When constructing a list or tuple you can insert zero or more elements from another list/tuple/sequence by inserting **expression*
- There can be an arbitrary number of * expressions in a tuple or list construction

Python shell

```
> A = (1, 2, 3)
> B = ['B', 'C']
> L = [A, B, 4, 5]
> L
| [(1, 2, 3), ['B', 'C'], 4, 5]
> len(L)
| 4
> L = [*A, *B, 4, 5]
> L
| [1, 2, 3, 'B', 'C', 4, 5]
> len(L)
| 7
> (*A, *B, 4, 5)
| (1, 2, 3, 'B', 'C', 4, 5)
```

Python shell

```
> from timeit import timeit
> timeit('A + A + A + A + A + A + A + A', setup='A = [1,2,3,4,5,6,7,8,9,10]')
| 0.665172699955292  # repeated concatenation can be slow
> timeit('[*A, *A, *A, *A, *A, *A, *A, *A]', setup='A = [1,2,3,4,5,6,7,8,9,10]')
| 0.3259985999027103  # * notation can be faster for multiple concatenation
```



list_catenation.py

```
import matplotlib.pyplot as plt
from timeit import timeit

ns = range(2, 101)
P, S = [], []
for n in ns:
    setup = 'A = list(range(10))'
    plus = ' + '.join(['A'] * n)
    star = '[' + ', '.join(['*A'] * n) + ']'
    P.append(timeit(plus, setup=setup))
    S.append(timeit(star, setup=setup))

plt.plot(ns, P, '.-', label='A + ... + A')
plt.plot(ns, S, '.-', label='[*A, ..., *A]')
plt.legend()
plt.ylabel('time (sec $10^{-6}$)')
plt.xlabel('number of As')
plt.show()
```

List comprehension (cool stuff)

- Example:

```
[x*x for x in [1, 2, 3]]
```

returns

```
[1, 4, 9]
```

- General

[expression for variable in sequence]

returns a list, where *expression* is computed for each element in *sequence* assigned to *variable*

Python shell

```
> [2*x for x in [1,2,3]]
| [2, 4, 6]
> [2*x for x in (1,2,3)]
| [2, 4, 6]
> [2*x for x in range(10,15)]
| [20, 22, 24, 26, 28]
> [2*x for x in 'abc']
| ['aa', 'bb', 'cc']
> [(None, None) for _ in range(2)]
| [(None, None), (None, None)]
```

List comprehension (it’s just syntactic sugar…)

Python shell

```
> [x * 2 for x in [1, 2, 3]]
| [2, 4, 6]

> L = []
> for x in [1, 2, 3]:
>     L.append(x * 2)
> L
| [2, 4, 6]
```

List comprehension (more cool stuff)

- Similarly, to the left-hand-side in assignments, the variable part can be a (nested) tuple of variables for unpacking elements:

[*expression* `for` *tuple of variables* `in` *sequence*]

Python shell

```
> points = [(3, 4), (2, 5), (4, 7)]
> [(x, y, x*y) for (x, y) in points]
| [(3, 4, 12), (2, 5, 10), (4, 7, 28)]
> [(x, y, x*y) for x, y in points]
| [(3, 4, 12), (2, 5, 10), (4, 7, 28)]
> [x, y, x*y for (x, y) in points]
| SyntexError: invalid syntax
```

parenthesis required for the constructed tuples

List comprehension – for-if and multiple for

- List comprehensions can have nested for-loops

  [*expression* `for` v_1 `in` s_1 `for` v_2 `in` s_2 `for` v_3 `in` s_3]

- Can select a subset of the elements by adding an if-condition

  [*expression* `for` v_1 `in` s_1 `if` *condition*]

- and be combined...

Python shell

```
> [(x, y) for x in range(1, 3) for y in range(4, 6)]
| [(1, 4), (1, 5), (2, 4), (2, 5)]
> [x for x in (1, 2) for x in (4, 5)]
| [4, 5, 4, 5]
> [x for x in range(1, 101) if x % 7 == 1 and x % 5 == 2]
| [22, 57, 92]
> [(x, y, x*y) for x in range(1, 11) if 6 <= x <= 7 for y in range(x, 11) if 6 <= y <= 7 and not x == y]
| [(6, 7, 42)]
```

Question – What will print the same?

```
points = [(3,7), (4,10), (12,3), (9,11), (7,5)]
print([(x, y) for x, y in points if x < y])
```

a) `print([x, y for x, y in points if x < y])`
b) `print([(x, y) for p in points if p[0] < p[1]])`
c) `print([p for p in points if p[0] < p[1]])`
d) `print([[x, y] for x, y in points if x < y])`
e) Don’t know

List comprehension – space usage long lists 

Bad: creates new tuples
(64 bytes per point)

Good: looks nice

list_comprehension_space_usage.py

```
input('press enter')
points = [(x, x + 1) for x in range(10_000_000)]  # dummy points
input('press enter')
selected = [(x, y) for (x, y) in points if y == x + 1]
input('press enter')
selected = [point for point in points if point[1] == point[0] + 1]
input('press enter')
```

3.7 MB

1305.6 MB

1997.3 MB

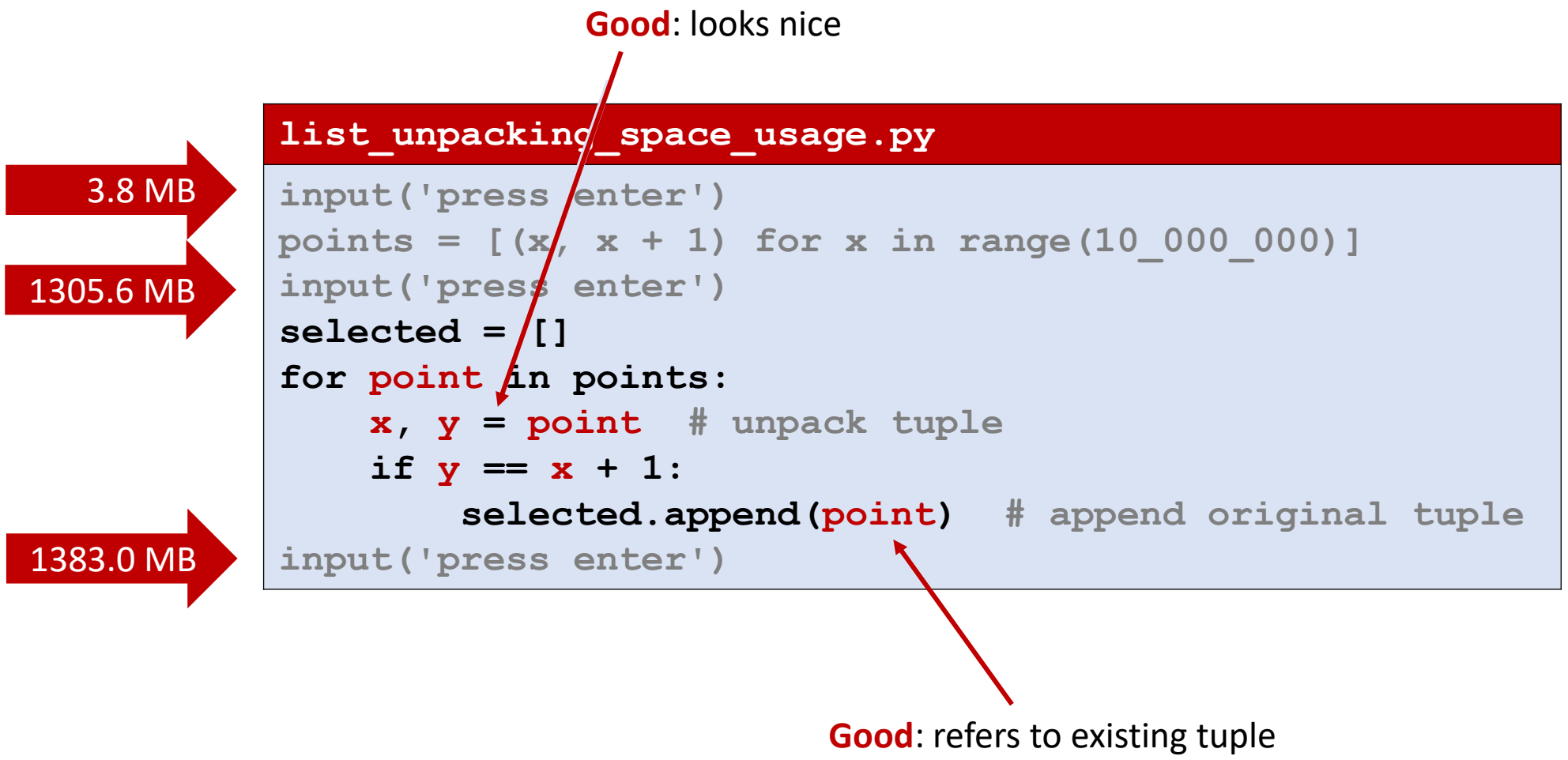
1387.3 MB

Good: refers to existing tuple
(8 bytes per point)

Bad: looks ugly (hard to read)

- Memory usage according to “Task Manager” in Windows
- Unpacking makes code more readable, but creating new tuples requires additional space…

Without comprehension (1 line becomes 5 lines)



any, all

- `any(L)` checks if at least one element in the sequence `L` is true (list, tuple, ranges, sequence, strings, ...)

```
any([False, True, False])
```

- `all(L)` checks if all elements in the sequence `L` are true

```
all([False, False, True])
```

- `any` and `all` return `True` or `False`

Python shell

```
> any((False, True, False))
| True
> any([False, False, False])
| False
> any([])
| False
> all([False, False, True])
| False
> all((True, True, True))
| True
> all(())
| True
> L = (7, 42, 13)
> any([x == 42 for x in L])
| True
> all([x == 42 for x in L])
| False
```

Example – computing primes

Python shell

```
> [x for x in range(2, 50) if all([x % f for f in range(2, x)])]
| [2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 47]

> [10 % f for f in range(2, 10)]
| [0, 1, 2, 0, 4, 3, 2, 1]
> all([10 % f for f in range(2, 10)])  #  == 0 is considered False
| False
> [13 % f for f in range(2, 13)]
| [1, 1, 1, 3, 1, 6, 5, 4, 3, 2, 1]
> all([13 % f for f in range(2, 13)])
| True
```

enumerate

`list(enumerate(L))`

returns

`[(0, L[0]), (1, L[1]), ..., (len(L) - 1, L[-1])]`

Python shell

```
> points = [(1, 2), (3, 4), (5, 6)]
> [(idx, x * y) for idx, (x, y) in enumerate(points)]
| [(0, 2), (1, 12), (2,30)]
> L = ('a', 'b', 'c')
> list(enumerate(L))
| [(0, 'a'), (1, 'b'), (2, 'c')]
> L_ = []
> for idx in range(len(L)):
>       L_.append((idx, L[idx]))
> print(L_)
| [(0, 'a'), (1, 'b'), (2, 'c')]
> list(enumerate(['a', 'b', 'c'], start=7))
| [(7, 'a'), (8, 'b'), (9, 'c')]
```

zip

`list(zip(`L_1`,`L_2`,…,`L_k`))` = [(L_1[0],L_2[0],…,L_k[0]), …, (L_1[*n*-1],L_2[*n*-1],…,L_k[*n*-1])]

where *n* = min(len(L_1), len(L_2),…, len(L_k))

- Example ("matrix transpose"):

```
list(zip([1,2,3],
         [4,5,6],
         [7,8,9]))
```

returns

```
[(1, 4, 7),
 (2, 5, 8),
 (3, 6, 9)]
```

Python shell

```
> x = [1, 2, 3]
> y = [4, 5, 6]
| zip(x, y)
> <zip at 0xb02b530>
> points = list(zip(x, y))
> print(points)
| [(1, 4), (2, 5), (3, 6)]
```

Python shell

```
> first = ['Donald', 'Mickey', 'Scrooge']
> last = ['Duck', 'Mouse', 'McDuck']

> for i, (a, b) in enumerate(zip(first, last), start=1):
>     print(i, a, b)

| 1 Donald Duck
| 2 Mickey Mouse
| 3 Scrooge McDuck
```

(Simple) functions

- You can define your own functions using:

  `def` *function-name* `(`var_1, ..., var_k`):`

  body code

- If the body code executes

  `return` *expression*

  the result of *expression* will be returned by the function. If expression is omitted or the body code terminates without performing `return`, then `None` is returned

- When *calling* a function *name* `(`$value_1$,..., $value_k$`)` body code is executed with var_i=$value_i$

Python shell

```
> def sum3(x, y, z):
      return x + y + z

> sum3(1, 2, 3)
| 6
> sum3(5, 7, 9)
| 21

> def powers(L, power):
      P = [x**power for x in L]
      return P

> powers([2, 3, 4], 3)
| [8, 27, 64]
```

Question – What tuple is printed ?

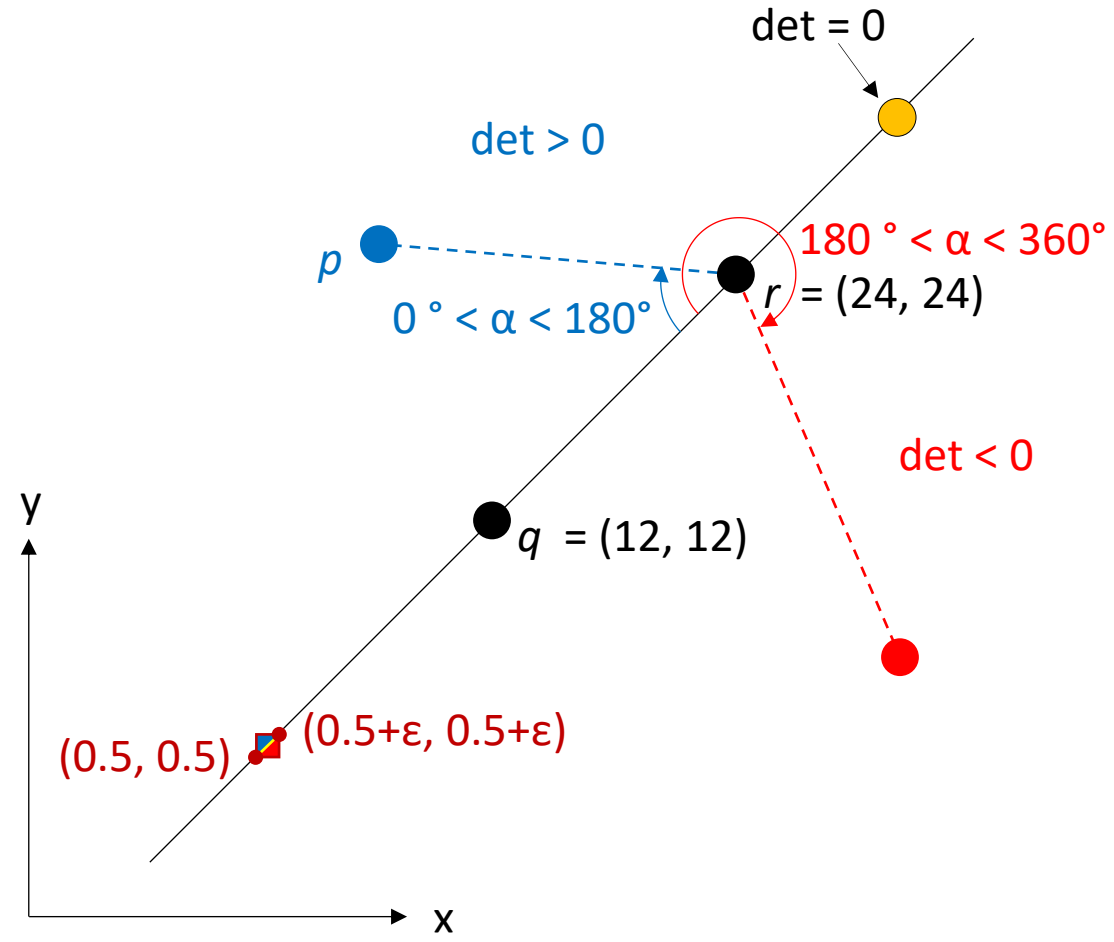
```
def even(x):
    if x % 2 == 0:
        return True
    else:
        return False

print((even(7), even(6)))
```

a) (False, False)
b) (False, True)
c) (True, False)
d) (True, True)
e) Don’t know

Geometric orientation test

Purpose of example

- illustrate tuples
- list comprehension
- matplotlib.pyplot
- floats are strange 

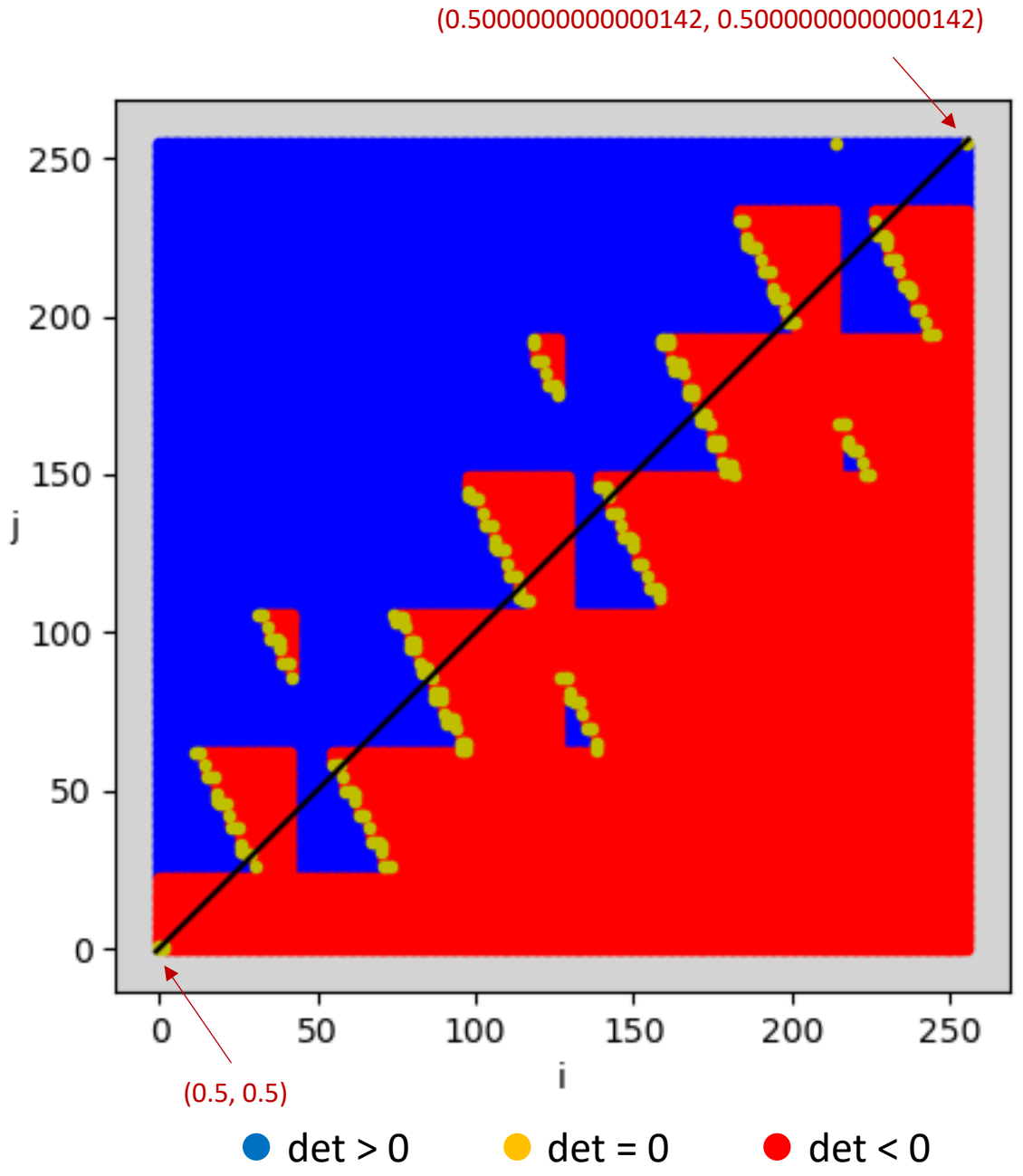


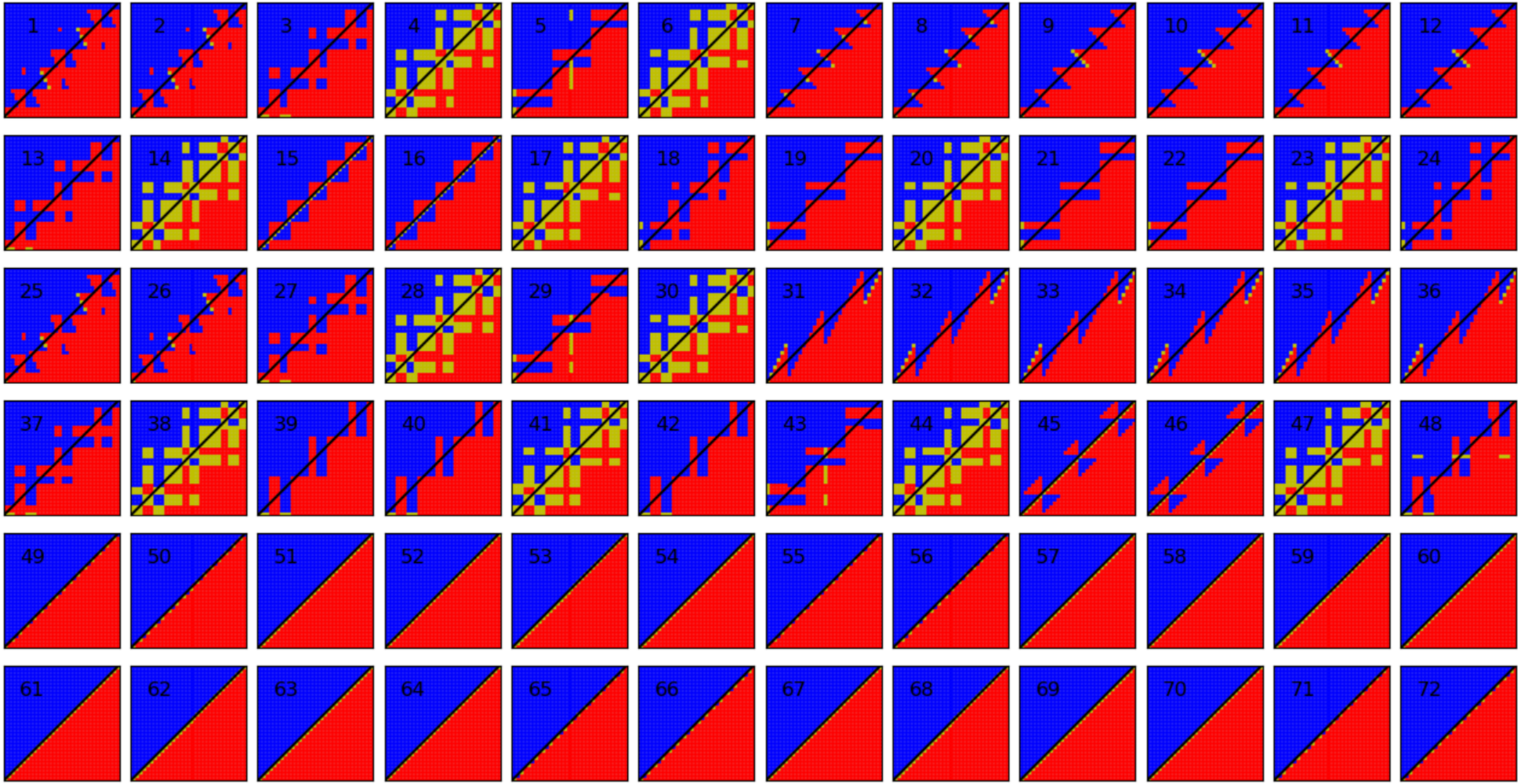
$$\det = \begin{vmatrix} 1 & q_x & q_y \\ 1 & r_x & r_y \\ 1 & p_x & p_y \end{vmatrix} = \underbrace{r_x p_y - p_x r_y - q_x p_y + p_x q_y + q_x r_y - r_x q_y}_{6\,! = 720 \text{ different orders to add}}$$

Kettner, Mehlhorn, Pion, Schirra, Yap:
Classroom Examples of Robustness Problems in Geometric Computations

sign-plot.py

```
import matplotlib.pyplot as plt

N = 256
delta = 1 / 2**54
q = (12, 12)
r = (24, 24)
P = []  # points (i, j, det)

for i in range(N):
    for j in range(N):
        p = (1/2 + i * delta, 1/2 + j * delta)
        det = (q[0]*r[1] + r[0]*p[1] + p[0]*q[1]
             - r[0]*q[1] - p[0]*r[1] - q[0]*p[1])
        P.append((i, j, det))

pos = [(i, j) for i, j, det in P if det > 0]
neg = [(i, j) for i, j, det in P if det < 0]
zero = [(i, j) for i, j, det in P if det == 0]

plt.subplot(facecolor='lightgrey', aspect='equal')
plt.xlabel('i')
plt.ylabel('j', rotation=0)

for points, color in [(pos, 'b'), (neg, 'r'), (zero, 'y')]:
    X = [i for i, j in points]
    Y = [j for i, j in points]
    plt.plot(X, Y, color + '. ')

plt.plot([-1, N], [-1, N], 'k-')
plt.show()
```

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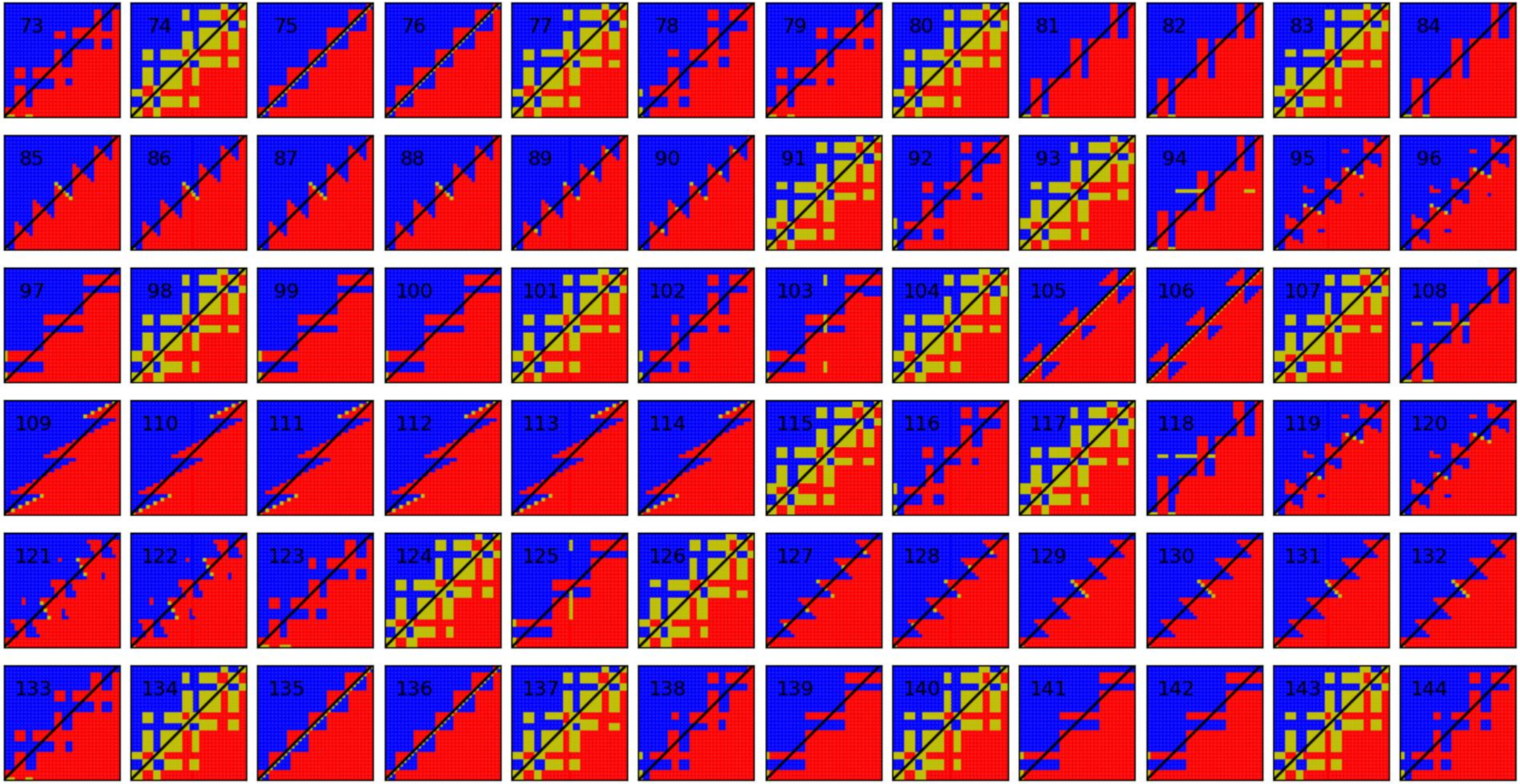
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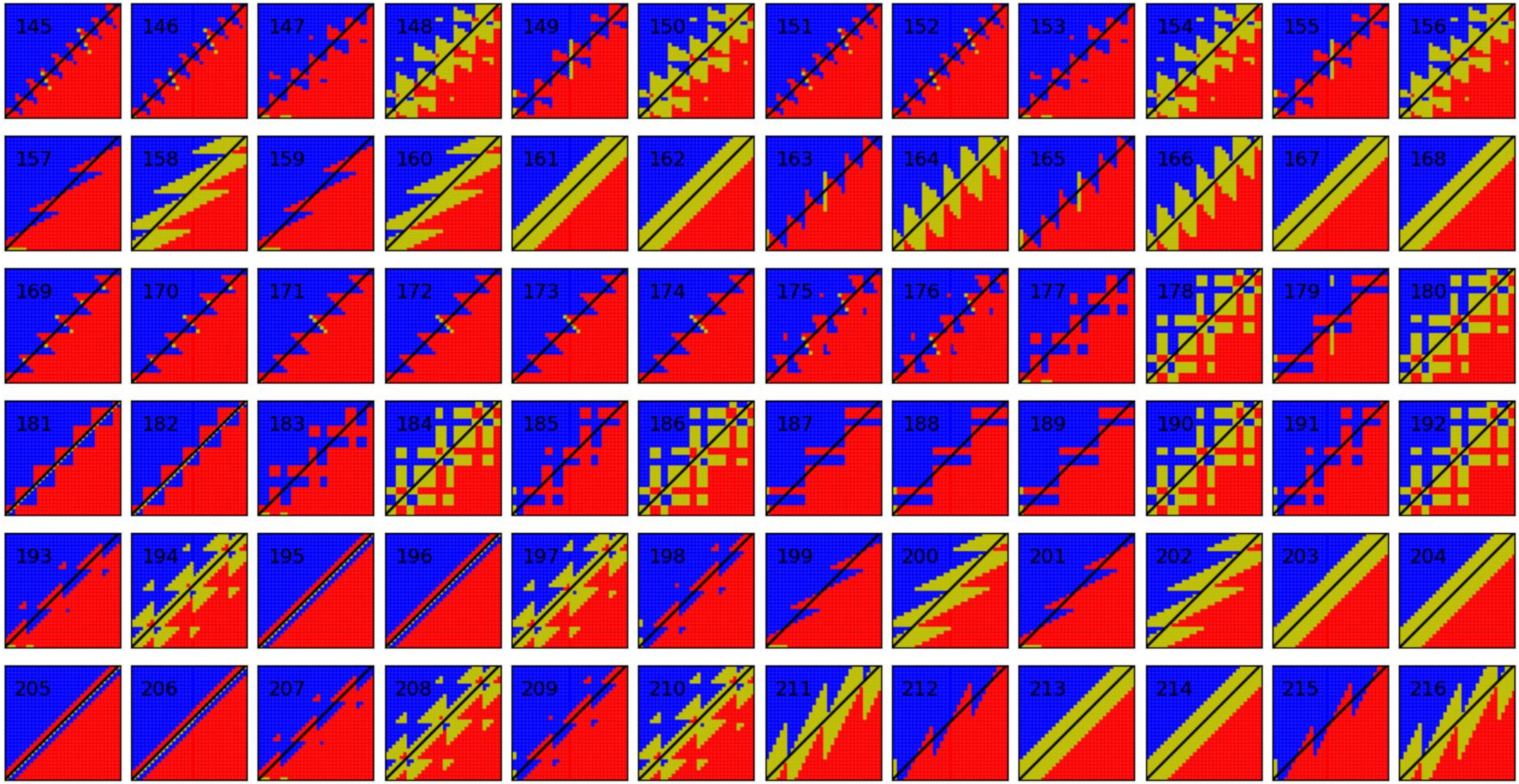
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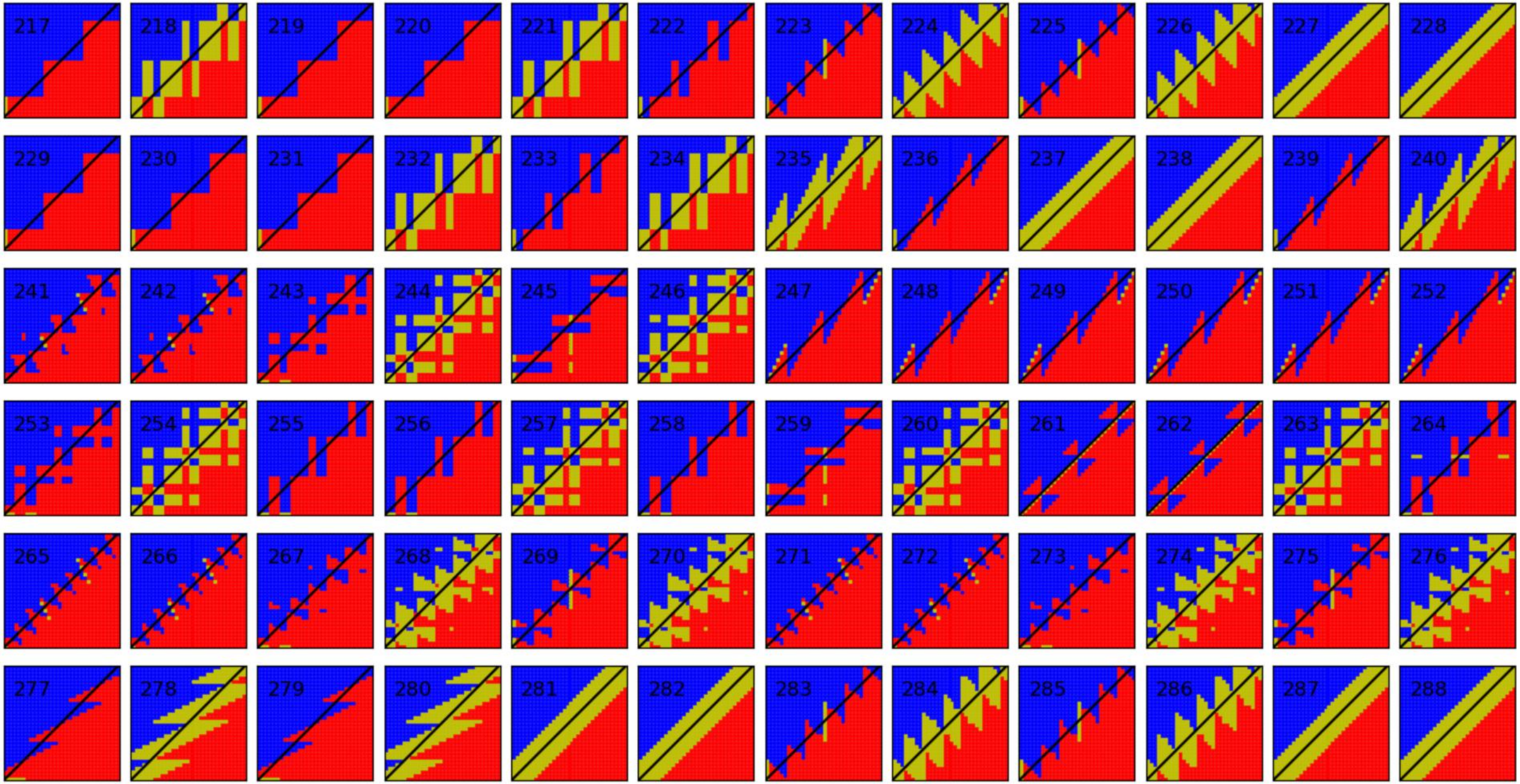
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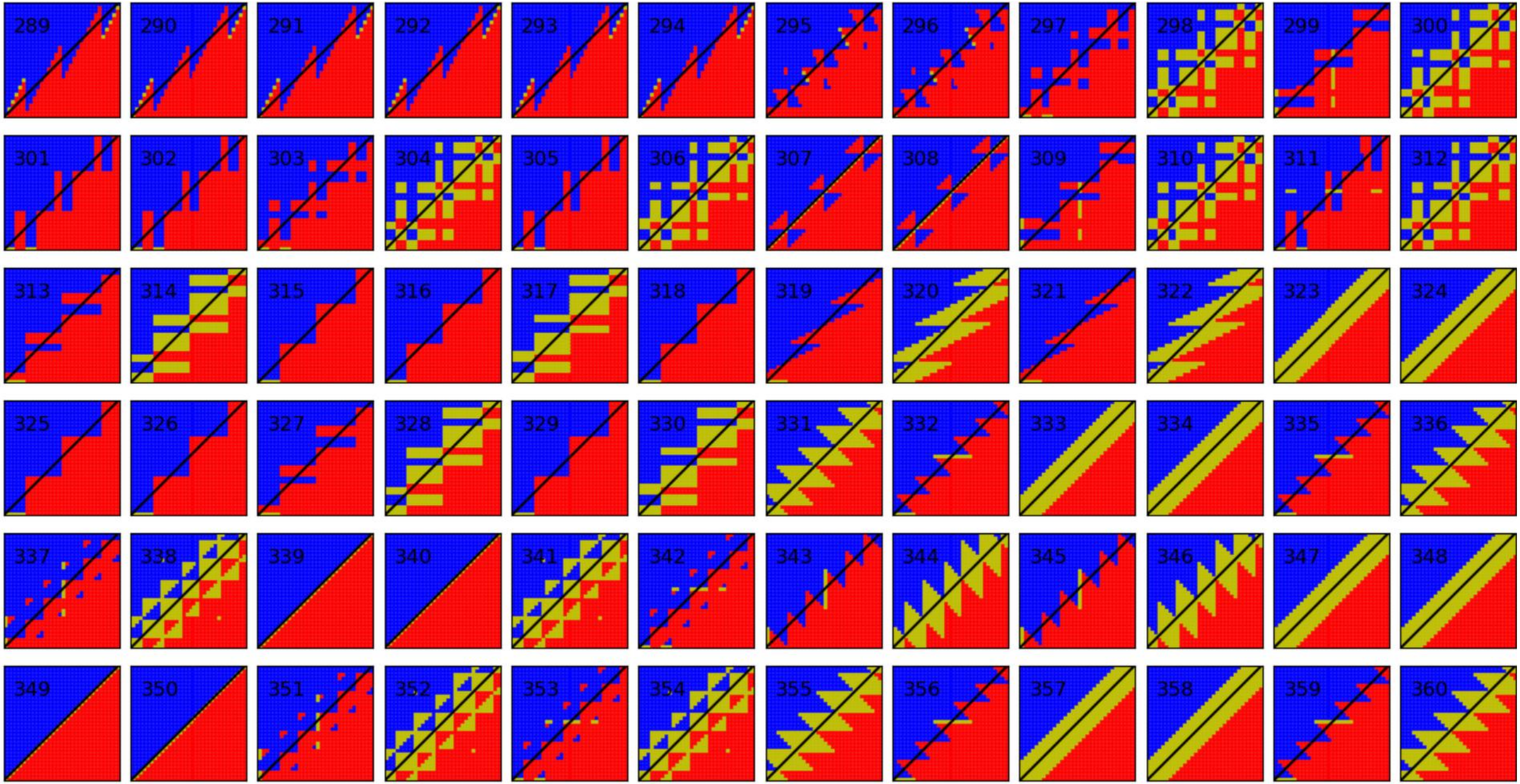
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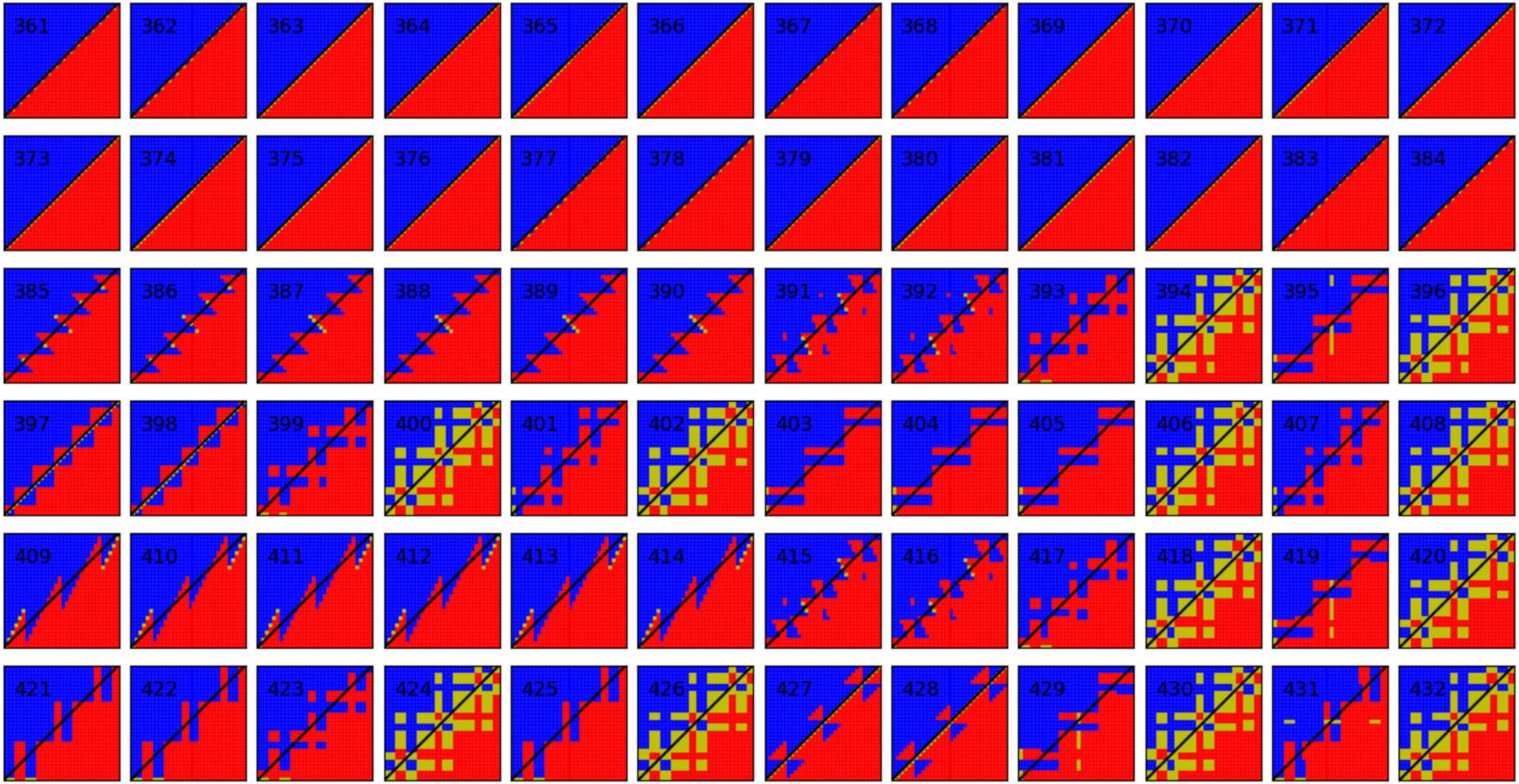
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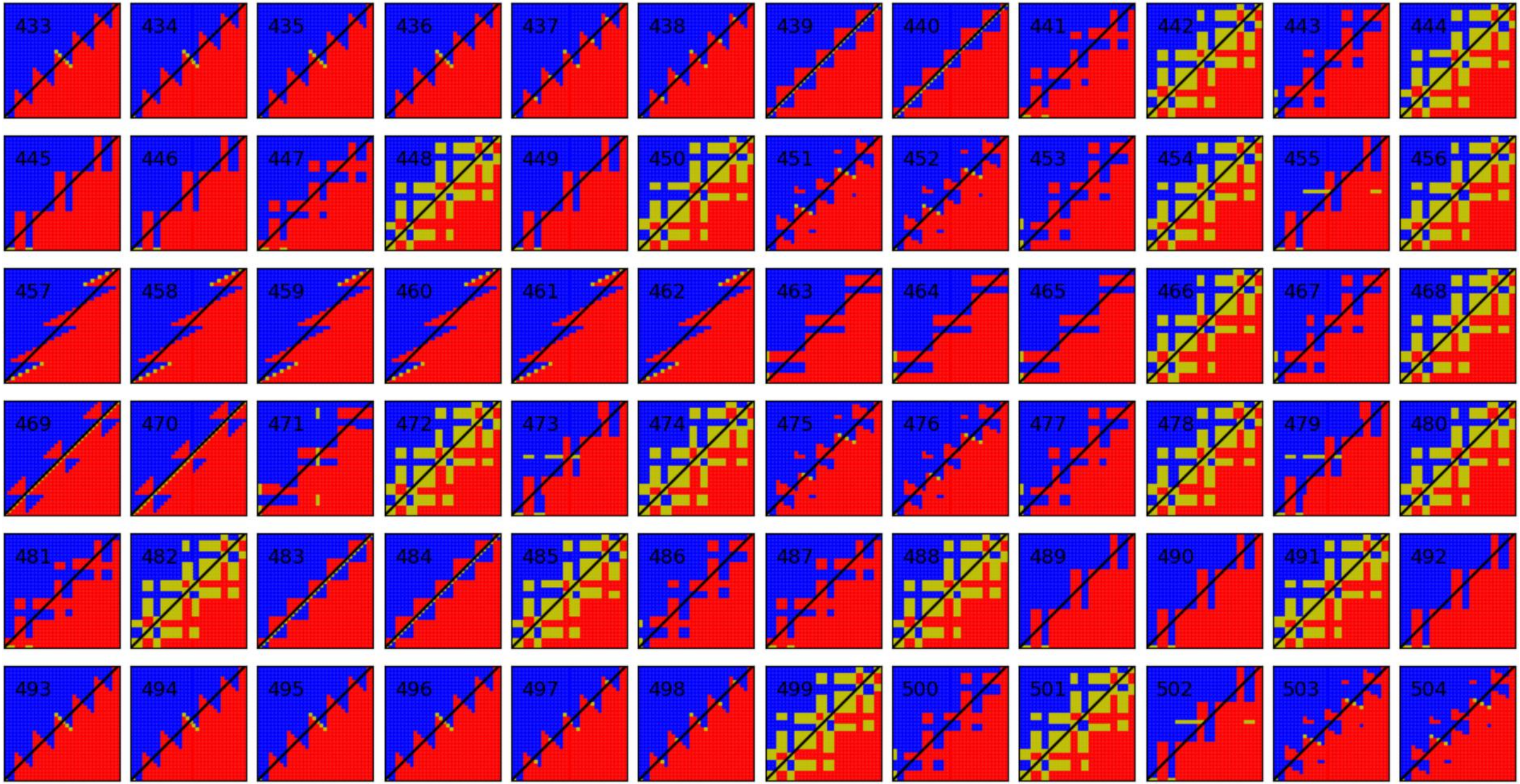
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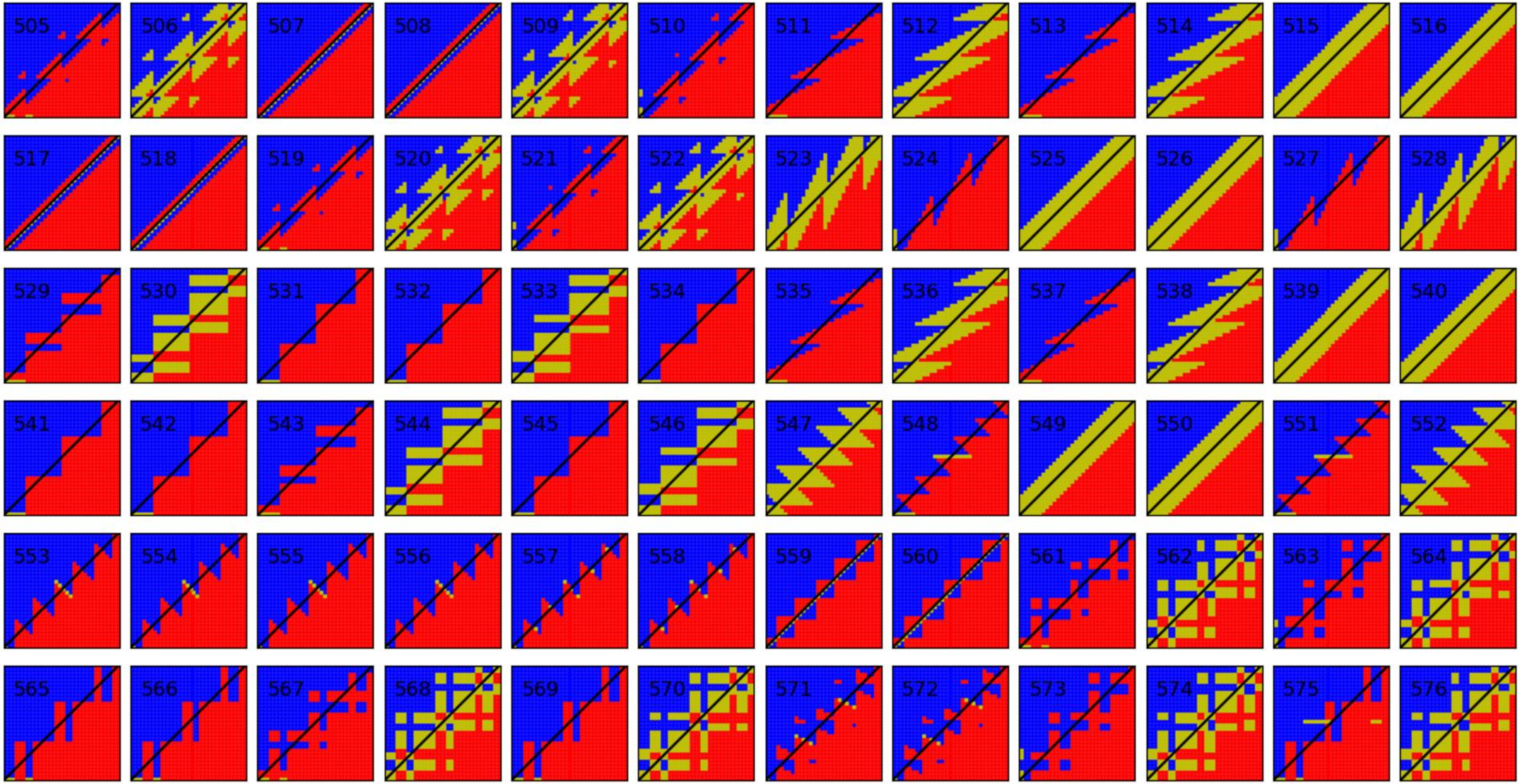
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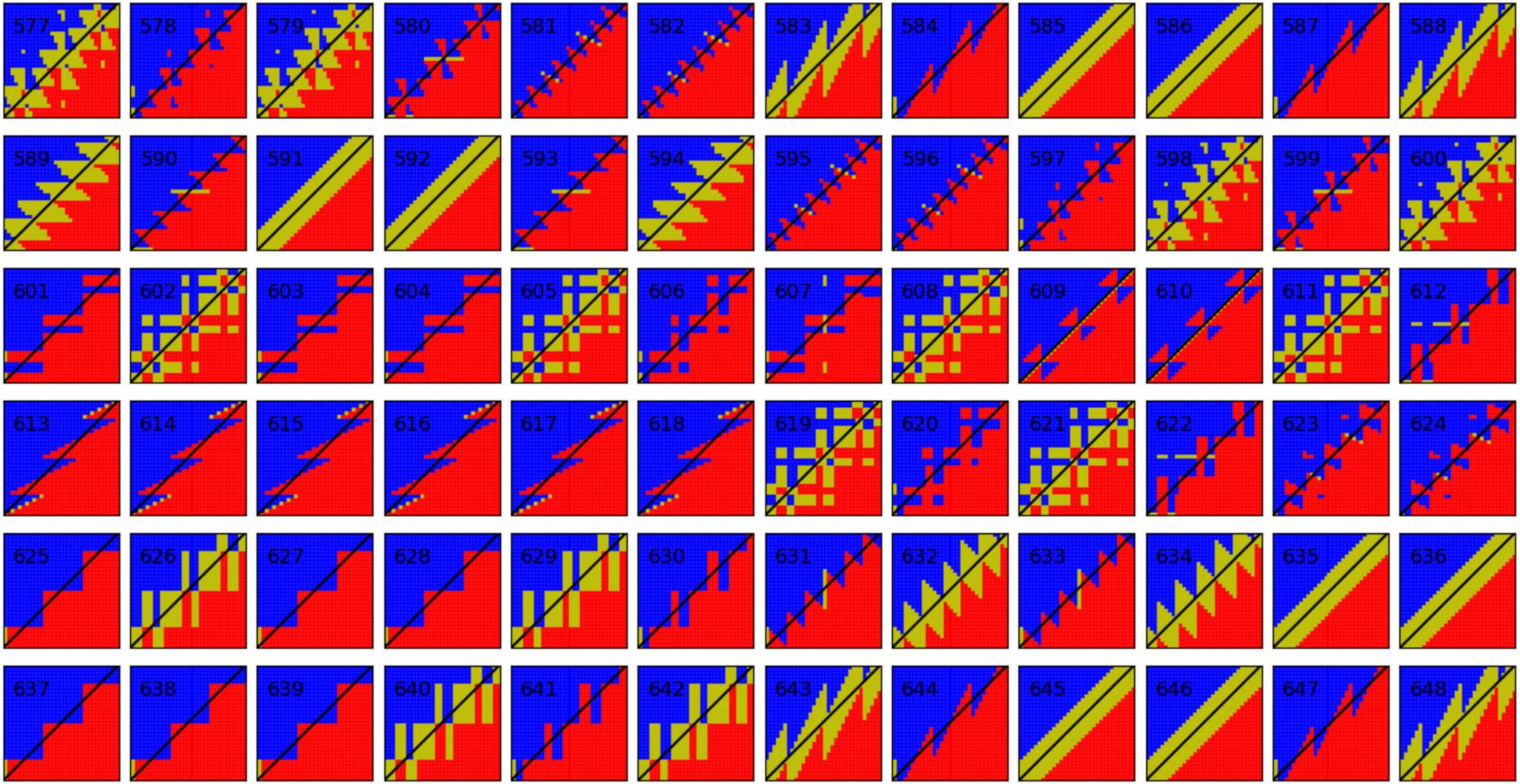
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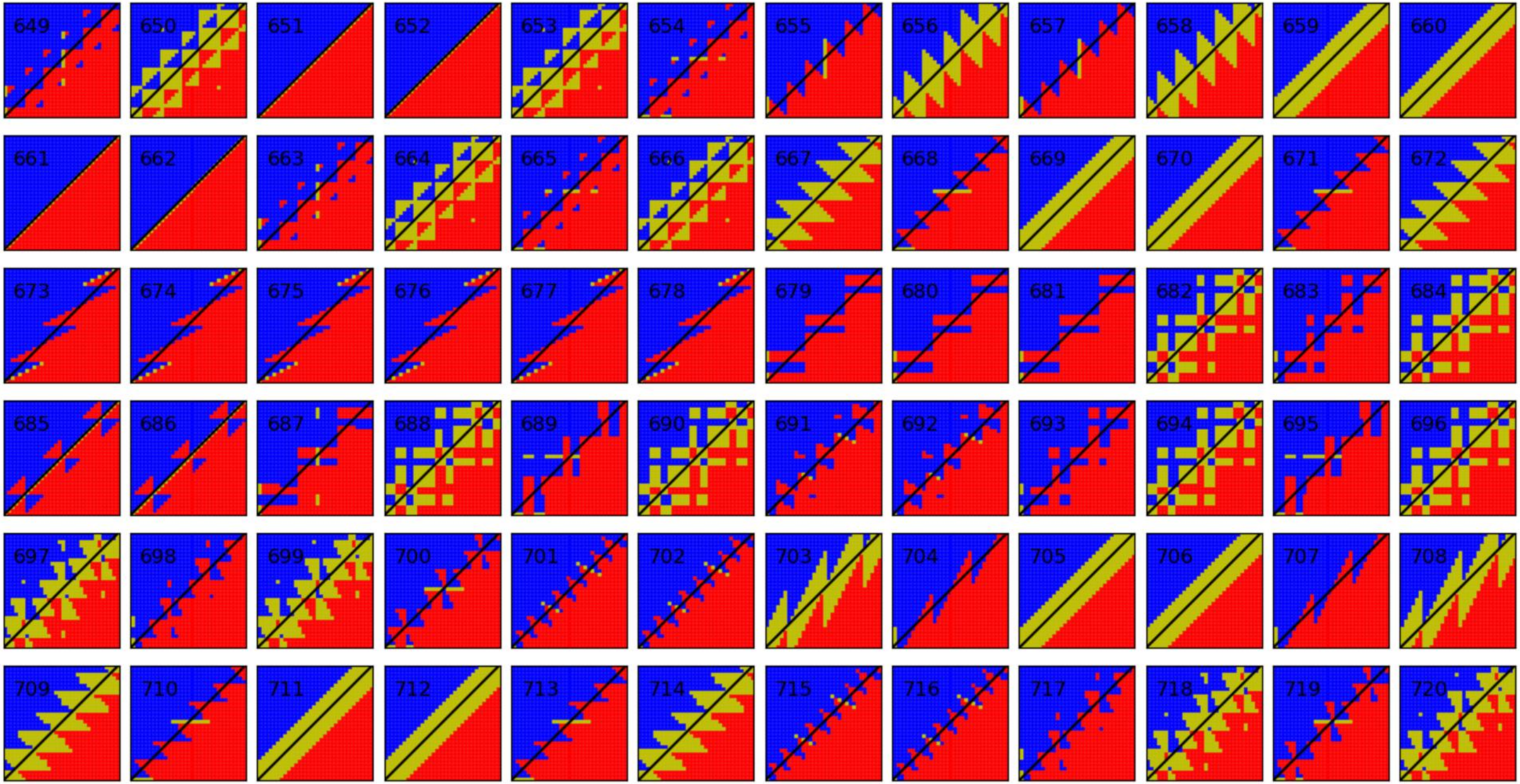
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