Gas-wasting Patterns Demonstrations

October 2023

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0.1 Pattern 1. Repeated computation of the same expression.

Table 1: Gas consumption table for pattern 1.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	231938	220290	**5.0220%**	27154	26391	**2.8098%**
Execution cost	166408	155602	**6.4936%**	6090	5327	**12.528%**

Listing 1: Unptimized example of Pattern 1

```
1
2  pragma solidity ^0.8.17;
3
4  contract OperaBaseTokenTaxed {
5      uint256 public _liquidityBuyTax;
6      uint256 public _liquiditySellTax;
7
8      function getTotalTax() internal view returns (uint) {
9          return 300;
10     }
11
12     function tokenSwap() public {
13         uint256 amount = 200;
14
15         uint256 amountToLiquify = (_liquidityBuyTax + _liquiditySellTax > 0)
16             ? amount * (_liquidityBuyTax + _liquiditySellTax) / getTotalTax() / 2
17             : 0;
18         uint256 totalETHFee = (_liquidityBuyTax + _liquiditySellTax > 0)
19             ? getTotalTax() - (_liquidityBuyTax + _liquiditySellTax) / 2
20             : getTotalTax();
21
22         uint256 amountETH = 100;
23         uint256 amountETHLiquidity = amountETH * (_liquidityBuyTax + _liquiditySellTax) / totalETHFee / 2;
24     }
25 }
```

Listing 2: Optimized example of Pattern 1

```
1
2  pragma solidity ^0.8.17;
3
4  contract OperaBaseTokenTaxed {
5      uint256 public _liquidityBuyTax;
6      uint256 public _liquiditySellTax;
7
8      function getTotalTax() internal view returns (uint) {
9          return 300;
10     }
11
12     function tokenSwap() public {
13         uint256 amount = 200;
14
15         uint256 taxSum = _liquidityBuyTax + _liquiditySellTax;
16         uint256 amountToLiquify = (taxSum > 0)
17             ? amount * (taxSum) / getTotalTax() / 2
18             : 0;
19         uint256 totalETHFee = (taxSum > 0)
20             ? getTotalTax() - (taxSum) / 2
21             : getTotalTax();
22
23         uint256 amountETH = 100;
24         uint256 amountETHLiquidity = amountETH * (taxSum) / totalETHFee / 2;
25     }
26 }
```

1. Pattern explanation. This pattern occurs when there are multiple repetitions of the same costly expression (e.g. mathematical or logical expressions, calls to the same external functions that would produce the same effect, reading from the same storage variable (note that reading from storage variables is a very gas-expensive operation in Solidity), etc). This pattern wastes gas because it performs the same evaluations multiple times. To address it, we could evaluate the repeated costly expression by just once, store its result in an intermediate memory variable, and then replace other repetitions of the same expression by the cached value.

2. Example. To further illustrate this pattern, we take as an example the function *tokenSwap* of the contract *OperaBaseTokenTaxed*, which is deployed at *0x0586638503CCaA365cD8a1338f3b84C54BAe65B3*. The unoptimized codes are shown in Listing 1 and the optimized version is in Listing 2. In addition,

the gas consumption result is listed in Table 1 [1]. It can be observed that the code segment *_liquidityBuyTax + _liquiditySellTax* is repeated 5 times in the presented codes, where 4 such additions could be saved by caching the result of *_liquidityBuyTax + _liquiditySellTax* in an intermediate variable. The gas saving comes from turn accesses to storage variables into memory variables, which is much cheaper.

[1] Note that in this report, $\mathscr{D}_i$ stands for deployment costs, $\mathscr{R}_i$ stands for message call costs, where $i \in \{u, o\}$ with u standing for the unoptimized version and o for the optimized one.

0.2 Pattern 2. Extractable code chunks.

Table 2: Gas consumption table for pattern 2.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	590280	518438	**12.170%**	30306	30369	**-0.207%**
Execution cost	500672	433810	**13.354%**	7958	8021	**-0.791%**

Listing 3: Unptimized example of Pattern 2

```
1
2  pragma solidity ^0.8.13;
3  error OperatorNotAllowed(address a);
4
5  contract IOperatorFilterRegistry {
6      function isOperatorAllowed(address a, address b) public returns (bool) {
7          return true;
8      }
9  }
10
11 contract HolographDropERC721 {
12     IOperatorFilterRegistry public openseaOperatorFilterRegistry =
13         new IOperatorFilterRegistry();
14
15     function msgSender() public returns (address) {
16         return address(this);
17     }
18
19     function beforeSafeTransfer(
20         address _from,
21         address, /* _to*/
22         uint256, /* _tokenId*/
23         bytes calldata /* _data*/
24     ) external returns (bool) {
25         if (
26             _from != address(0) && // skip on mints
27             _from != msgSender() // skip on transfers from sender
28         ) {
29             bool osRegistryEnabled;
30             assembly {
31                 osRegistryEnabled := sload(osRegistryEnabled)
32             }
33             if (osRegistryEnabled) {
34                 try
35                     openseaOperatorFilterRegistry.isOperatorAllowed(
36                         address(this),
37                         msgSender()
38                     )
39                 returns (bool allowed) {
40                     return allowed;
41                 } catch {
42                     revert OperatorNotAllowed(msgSender());
43                 }
44             }
45         }
46         return true;
47     }
48
49     function beforeTransfer(
50         address _from,
51         address, /* _to*/
52         uint256, /* _tokenId*/
53         bytes calldata /* _data*/
54     ) external returns (bool) {
55         if (
56             _from != address(0) && // skip on mints
57             _from != msgSender() // skip on transfers from sender
58         ) {
59             bool osRegistryEnabled;
60             assembly {
61                 osRegistryEnabled := sload(osRegistryEnabled)
62             }
63             if (osRegistryEnabled) {
64                 try
65                     openseaOperatorFilterRegistry.isOperatorAllowed(
66                         address(this),
67                         msgSender()
68                     )
69                 returns (bool allowed) {
70                     return allowed;
71                 } catch {
72                     revert OperatorNotAllowed(msgSender());
73                 }
74             }
75         }
76         return true;
77     }
78 }
```

Listing 4: Optimized example of Pattern 2

```
pragma solidity ^0.8.13;
error OperatorNotAllowed(address a);

contract IOperatorFilterRegistry {
    function isOperatorAllowed(address a, address b) public returns (bool) {
        return true;
    }
}

contract HolographDropERC721 {
    IOperatorFilterRegistry public openseaOperatorFilterRegistry =
        new IOperatorFilterRegistry();

    function beforeTransferNew(
        address _from,
        address, /* _to*/
        uint256, /* _tokenId*/
        bytes calldata /* _data*/
    ) internal returns (bool) {
        if (
            _from != address(0) && // skip on mints
            _from != msgSender() // skip on transfers from sender
        ) {
            bool osRegistryEnabled;
            assembly {
                osRegistryEnabled := sload(osRegistryEnabled)
            }
            if (osRegistryEnabled) {
                try
                    openseaOperatorFilterRegistry.isOperatorAllowed(
                        address(this),
                        msgSender()
                    )
                returns (bool allowed) {
                    return allowed;
                } catch {
                    revert OperatorNotAllowed(msgSender());
                }
            }
        }
        return true;
    }

    function msgSender() public returns (address) {
        return address(this);
    }

    function beforeSafeTransfer(
        address _from,
        address _to,
        uint256 _tokenId,
        bytes calldata _data
    ) external returns (bool) {
        return beforeTransferNew(_from, _to, _tokenId, _data);
    }

    function beforeTransfer(
        address _from,
        address _to,
        uint256 _tokenId,
        bytes calldata _data
    ) external returns (bool) {
        return beforeTransferNew(_from, _to, _tokenId, _data);
    }
}
```

1. Pattern explanation. This pattern occurs when there are multiple repetitions of the same chunk of codes across multiple functions or within one single function. This pattern wastes gas because the high repitition of codes would increase the cost to deploy the contract. To address this pattern, we could extract the repeated chunks of codes into a separate function, and replace the original chunks of codes by a call to the function. This largely reduced the amount of codes to be deployed, and thus saves deployment gas costs.

2. Example. To further illustrate this pattern, we take as an example the function *beforeSafeTransfer* of the contract *IOperatorFilterRegistry*, which is deployed at *0x257dab74AB23BBF2018C088A29991714ee124F97*. The unoptimized codes are shown in Listing 3 and the optimized version is in Listing 4. In addition, the gas consumption result is listed in Table 2. It can be observed that the functions *beforeSafeTransfer* and *beforeTransfer* have identical code segments, and it would be more maintainbale, readable, as well as gas-efficient if we extract their codes into a new function *beforeTransferNew* and instead call the new function directly. The benefit of maintainability comes from the fact that

future amendments to the codes only need to be performed on one function (i.e. the new function *beforeTransferNew*), instead of to both *beforeSafeTransfer* and *beforeTransfer*. The benefits of gas efficiency comes from saving the amount of bytecodes that need to be stored on-chain as well as from a lower cost of the CODECOPY instruction during deployment.

0.3 Pattern 3. State Variable Refactoring.

Table 3: Gas consumption table for pattern 3.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	207710	197484	**4.9232%**	34046	24173	**28.999%**
Execution cost	146106	130506	**10.677%**	12982	3109	**76.051%**

Listing 5: Unptimized example of Pattern 3

```
1
2  pragma solidity ^0.8.0;
3
4  contract PumpNft {
5      uint256 public gStartsAt;
6      uint256 public gEndsAt;
7      uint256 public fcfsStartsAt;
8      uint256 public fcfsEndsAt;
9      uint256 public publicStartsAt;
10     uint256 public publicEndsAt = type(uint256).max;
11
12     constructor(
13         uint256 _gStartsAt,
14         uint256 _gEndsAt,
15         uint256 _fcfsStartsAt,
16         uint256 _fcfsEndsAt,
17         uint256 _publicStartsAt
18     ) {
19         gStartsAt = _gStartsAt;
20         gEndsAt = _gEndsAt;
21         fcfsStartsAt = _fcfsStartsAt;
22         fcfsEndsAt = _fcfsEndsAt;
23         publicStartsAt = _publicStartsAt;
24     }
25
26     function currentStage() public returns (uint256 stage) {
27         if (block.timestamp >= gStartsAt && block.timestamp <= gEndsAt) {
28             return 1;
29         }
30
31         if (block.timestamp >= fcfsStartsAt && block.timestamp <= fcfsEndsAt) {
32             return 2;
33         }
34
35         if (
36             block.timestamp >= publicStartsAt && block.timestamp <= publicEndsAt
37         ) {
38             return 3;
39         }
40
41         return 0;
42     }
43 }
```

Listing 6: Optimized example of Pattern 3

```
1
2  pragma solidity ^0.8.0;
3
4  contract PumpNfto {
5      uint32 public gStartsAt;
6      uint32 public gEndsAt;
7      uint32 public fcfsStartsAt;
8      uint32 public fcfsEndsAt;
9      uint32 public publicStartsAt;
10     uint32 public publicEndsAt = type(uint32).max;
11
12     constructor(
13         uint32 _gStartsAt,
14         uint32 _gEndsAt,
15         uint32 _fcfsStartsAt,
16         uint32 _fcfsEndsAt,
17         uint32 _publicStartsAt
18     ) {
19         gStartsAt = _gStartsAt;
20         gEndsAt = _gEndsAt;
21         fcfsStartsAt = _fcfsStartsAt;
22         fcfsEndsAt = _fcfsEndsAt;
23         publicStartsAt = _publicStartsAt;
24     }
25
26     function currentStage() public returns (uint256 stage) {
27         if (block.timestamp >= gStartsAt && block.timestamp <= gEndsAt) {
28             return 1;
29         }
```

```
30
31          if (block.timestamp >= fcfsStartsAt && block.timestamp <= fcfsEndsAt) {
32              return 2;
33          }
34
35          if (block.timestamp >= publicStartsAt && block.timestamp <= publicEndsAt) {
36              return 3;
37          }
38
39          return 0;
40      }
41  }
```

1. Pattern explanation. This pattern seeks to specifically rearrange the layout of the state variables in storage to a more compact form by changing the type of variables (e.g. uint256 to uint32), while ensuring that the changed variable type is still compatible with the task at hand.

2. Example. To further illustrate this pattern, we take as an example the function *currentStage* of the contract *PumpNft*, which is deployed at *0xE3C7b06e06EAc93C9E3B11ea315C838A90CFB4ab*. The unoptimized codes are shown in Listing 5 and the optimized version is in Listing 6. In addition, the gas consumption result is listed in Table 3.

It can be observed that the variables *gStartsAt*, *gEndsAt*, *fcfsStartsAt*, *fcfsEndsAt*, *publicStartsAt*, *publicEndsAt* are all state variables of the PumpNft contract, and are all declared as **unit256**. However, since these variables are used as Unix timestamps to be compared to block timestamps, 256 bits would be too large for this purpose. As a reference, existing mature systems like MariaDB [5] and MongoDB [1] use 4 bytes to store timestamps. Therefore, it is not only safe but also enough to reduce the uint256 data type of the afroementioned state variables to uint32 in this example. Our experiment shows that this contributes to a significant saving of gas (i.e. a saving of 10.677% deployment gas and 76.051% message call gas). In particular, the gas saving comes from repeated warm accesses to the same address in the optimized codes. To be more specific, in the *currentStage* function of the unoptimized contract, since the state variables are declared as uint256, each would occupy a different storage slot. Because of this, during execution, the six accesses to each of the state variables are cold and would cost $12600 = 2100 \times 6$ gas in total. On the other hand, in the optimized version, the six state variables are packed into the same storage slot since each is of a small size of 4 bytes and they altogether could fit in one slot. This means that only the first access to one of the state variables is cold (i.e. access to *gStartsAt*), and all subsequent ones are warm. This way, the cost gets reduced to $2600 = 2100 + 100 \times 5$ gas, which is much lower than the unoptimized version.

0.4 Pattern 4. Redundant operations with same effects.

Table 4: Gas consumption table for pattern 4.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	275399	275399	**0.0%**	23647	23631	**0.0676%**
Execution cost	206851	206851	**0.0%**	1847	1831	**0.8662%**

Listing 7: Unptimized example of Pattern 4

```
1
2  pragma solidity ^0.8.18;
3
4  contract InitialFairOffering {
5      int24 public constant TICK_SPACING = 60; // Tick space is 60
6
7      function getInitialRate (uint, uint, uint, uint) internal returns (uint) {
8          return 1;
9      }
10
11     function priceToSqrtPriceX96(int, int24) internal returns (uint160) {
12         return 1;
13     }
14
15     function _initializePool(
16         address _weth,
17         address _token
18     )
19         public
20         returns (
21             address _token0,
22             address _token1,
23             uint _uintRate,
24             uint160 _sqrtPriceX96,
25             address _pool
26         )
27     {
28         _token0 = _token;
29         _token1 = _weth;
30
31         _uintRate = getInitialRate(
32             100,
33             200,
34             300,
35             400
36         ); // weth quantity per token
37         require(_uintRate > 0, "uint rate zero");
38
39         if (_token < _weth) {
40             _sqrtPriceX96 = priceToSqrtPriceX96(
41                 int(_uintRate),
42                 TICK_SPACING
43             );
44         } else {
45             _token0 = _weth;
46             _token1 = _token;
47             _uintRate = 10 ** 36 / _uintRate; // token quantity per weth
48             _sqrtPriceX96 = priceToSqrtPriceX96(
49                 int(_uintRate),
50                 TICK_SPACING
51             );
52         }
53     }
54
55 }
```

Listing 8: Optimized example of Pattern 4

```
1
2  pragma solidity ^0.8.18;
3
4  contract InitialFairOffering {
5      int24 public constant TICK_SPACING = 60; // Tick space is 60
6
7      function getInitialRate (uint, uint, uint, uint) internal returns (uint) {
8          return 1;
9      }
10
11     function priceToSqrtPriceX96(int, int24) internal returns (uint160) {
12         return 1;
13     }
14
15     function _initializePool(
16         address _weth,
17         address _token
```

```
18      )
19          public
20          returns (
21              address _token0,
22              address _token1,
23              uint _uintRate,
24              uint160 _sqrtPriceX96,
25              address _pool
26          )
27      {
28          _uintRate = getInitialRate(
29              100,
30              200,
31              300,
32              400
33          ); // weth quantity per token
34          require(_uintRate > 0, "uint rate zero");
35
36          if (_token < _weth) {
37              _token0 = _token;
38              _token1 = _weth;
39              _sqrtPriceX96 = priceToSqrtPriceX96(
40                  int(_uintRate),
41                  TICK_SPACING
42              );
43          } else {
44              _token0 = _weth;
45              _token1 = _token;
46              _uintRate = 10 ** 36 / _uintRate; // token quantity per weth
47              _sqrtPriceX96 = priceToSqrtPriceX96(
48                  int(_uintRate),
49                  TICK_SPACING
50              );
51          }
52      }
53
54  }
```

1. Pattern explanation. This pattern occurs when there are operations that overwrite the effect of the previous ones, where the previous effect was not utilized in anywhere, rendering the previous one useless. This pattern wastes gas because the repeated computations could be removed without affecting the functionality of the codes.

2. Example. To further illustrate this pattern, we take as an example the function *_initializePool* of the contract *InitialFairOffering*, which is deployed at *0x62700eA68B3DF1Bff05c596734f976f0AD901A4E*. The unoptimized codes are shown in Listing 7 and the optimized version is in Listing 8. In addition, the gas consumption result is listed in Table 4. It can be observed that in the _initializePool function, _token0 and _token1 are assigned values twice under certain conditions (i.e. if the "else" branch is taken). This redundant assignment wastes gas because it overwrites the initial assignments unnecessarily. Instead of assigning _token0 and _token1 at the beginning of the function, we can use a conditional assignment to assign them only once. This way, we could save the gas cost of an additional assignment. In particular, this is done by moving the lines *_token0 = _token;* and *_token1 = _weth;* into the beginning of the if branch.

0.5 Pattern 5. Pre-computable operations on constants.

Table 5: Gas consumption table for pattern 5.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	305335	293031	**4.0296%**	23584	23288	**1.2550%**
Execution cost	234675	223263	**4.8628%**	2028	1732	**14.595%**

Listing 9: Unptimized example of Pattern 5

```
1
2  pragma solidity ^0.8.0;
3
4  contract UNCX_ProofOfReservesV2_UniV3 {
5      event onRemoveFee(bytes32);
6      function contains (bytes32) internal returns (bool) {
7          return true;
8      }
9
10     function remove (bytes32) internal returns (bool) {
11         return true;
12     }
13
14     function removeFee (string memory _name) external {
15         bytes32 nameHash = keccak256(abi.encodePacked(_name));
16         require(nameHash != keccak256(abi.encodePacked("DEFAULT")), "DEFAULT");
17         require(contains(nameHash));
18         remove(nameHash);
19         emit onRemoveFee(nameHash);
20     }
21 }
```

Listing 10: Optimized example of Pattern 5

```
1
2  pragma solidity ^0.8.0;
3
4  contract UNCX_ProofOfReservesV2_UniV3 {
5      event onRemoveFee(bytes32);
6      function contains (bytes32) internal returns (bool) {
7          return true;
8      }
9
10     function remove (bytes32) internal returns (bool) {
11         return true;
12     }
13
14     function removeFee (string memory _name) external {
15         bytes32 nameHash = keccak256(abi.encodePacked(_name));
16         require(nameHash != 0x9F28225C7D0ACE67FA2516BD7725F3949E9A591DE0EAE9DB822B2CB79F38A6B0, "DEFAULT");
17         require(contains(nameHash));
18         remove(nameHash);
19         emit onRemoveFee(nameHash);
20     }
21 }
```

1. Pattern explanation. This pattern occurs when there are operations (e.g. logical comparisons, mathematical operations, a keccak256 hash operation on constants, etc) that are performed on constants whose values could be inferred without being compiled. This pattern wastes gas because such computations could be carried out before deploying the contract, which saves the gas consumption during runtime.

2. Example. To further illustrate this pattern, we take as an example the function *removeFee* of the contract *UNCX_ProofOfReservesV2_UniV3*, which is deployed at *0x7f5C649856F900d15C83741f45AE46f5C6858234*. The unoptimized codes are shown in Listing 9 and the optimized version is in Listing 10. In addition, the gas consumption result is listed in Table 5. It can be observed that there is a check of whether the variable *nameHash* (i.e. the hash of the input string *_name*) is the same as the hash of the string "DEFAULT". In other words, it is checking if the input variable *_name* has the same hashcode as the string "DEFAULT". Note that each time the comparison is done, the string "DEFAULT" is first encoded and then hashed; this is highly repetitive since the hashcode could be computed offline and placed in the codes directly. To save gas, we directly replace the codes *keccak256(abi.encodePacked("DEFAULT"))* by the corresponding hashcode of "DEFAULT" (i.e.

0x9F28225C7D0ACE67FA2516BD7725F3949E9A591DE0EAE9DB822B2CB79F38A6B0). One might argue that this constitutes a compromise to code readability, but a line of comment could be readily added to elaborate the purpose of this line of code, which still maximally retains the clarity without compromising gas costs.

0.6 Pattern 6. Deterministic conditional checks.

Table 6: Gas consumption table for pattern 6.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	243762	240078	**1.5113%**	23691	23651	**0.1688%**
Execution cost	177820	174420	**1.9120%**	2487	2447	**1.6083%**

Listing 11: Unptimized example of Pattern 6

```
1
2  pragma solidity ^0.8.18;
3
4  contract InitialFairOffering {
5      function addLiquidity(uint16 slippage) public {
6          uint256 balanceOfWeth = 100;
7          uint256 liquidityEtherPercent = 200;
8          uint256 maxRollups = 300;
9          uint256 fundingCommission = 400;
10         uint256 crowdFundingRate = 500;
11
12
13         require(slippage >= 0 && slippage <= 10000, "slippage error");
14
15         // Send ether back to deployer, the eth liquidity is based on the balance of this contract. So,
               anyone can send eth to this contract
16         uint256 backToDeployAmount = (balanceOfWeth *
17             (10000 - liquidityEtherPercent)) / 10000;
18         uint256 maxBackToDeployAmount = (maxRollups *
19             (10000 - fundingCommission) *
20             crowdFundingRate *
21             (10000 - liquidityEtherPercent)) / 100000000;
22
23     }
24 }
```

Listing 12: Optimized example of Pattern 6

```
1
2  pragma solidity ^0.8.18;
3
4  contract InitialFairOffering {
5      function addLiquidity(uint16 slippage) public {
6          uint256 balanceOfWeth = 100;
7          uint256 liquidityEtherPercent = 200;
8          uint256 maxRollups = 300;
9          uint256 fundingCommission = 400;
10         uint256 crowdFundingRate = 500;
11
12
13         require(slippage <= 10000, "slippage error");
14
15         // Send ether back to deployer, the eth liquidity is based on the balance of this contract. So,
               anyone can send eth to this contract
16         uint256 backToDeployAmount = (balanceOfWeth *
17             (10000 - liquidityEtherPercent)) / 10000;
18         uint256 maxBackToDeployAmount = (maxRollups *
19             (10000 - fundingCommission) *
20             crowdFundingRate *
21             (10000 - liquidityEtherPercent)) / 100000000;
22
23     }
24 }
```

1. Pattern explanation. This pattern occurs when some of the conditional checks always evaluate to either true or false. In other words, the value of such conditional expressions could be logically inferred (e.g. from variable types) without actually running the codes, regardless of the input values. This pattern wastes gas because the conditional expressions could be just replaced by the corresponding true/false value, without having to go through the actual computation.

2. Example. To further illustrate this pattern, we take as an example the function *addLiquidity* of the contract *InitialFairOffering*, which is deployed at *0x62700eA68B3DF1Bff05c596734f976f0AD901A4E*. The unoptimized codes are shown in Listing 11 and the optimized version is in Listing 12. In addition, the gas consumption result is listed in Table 6.

It can be observed that In the addLiquidity function, there's a check for $slippage >= 0$. Since slippage is a uint16, it can never be less than zero. Note that if we force the argument (i.e. slippage)

to be negative (e.g. -1), we would get the error: "transact to InitialFairOffering.addLiquidity errored: Error encoding arguments: Error: value out-of-bounds (argument=null, value="-1", code=INVALID_ARGUMENT, version=abi/5.7.0)." As a result, we could just remove this conditional check to save computation.

0.7 Pattern 7. Conditional statements with simpler equivalents.

Table 7: Gas consumption table for pattern 7.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	232355	228254	**1.7649%**	24142	24094	**0.1988%**
Execution cost	166957	163150	**2.2802%**	2798	2750	**1.7155%**

Listing 13: Unptimized example of Pattern 7

```
1
2  pragma solidity ^0.8.0;
3
4  contract presale {
5      address public presale_owner = 0x5B38Da6a701c568545dCfcB03FcB875f56beddC4;
6
7      function updateRatePresale(uint256 _rate, uint256 _rateStable) external {
8          bool isOwner = false;
9
10         if(msg.sender == presale_owner) {
11             isOwner = true;
12         }
13
14         require(isOwner == true, "Requires owner");
15
16         uint256 ratePresale; //listing price in wei
17         uint256 ratePresaleStable;
18
19         ratePresale = _rate;
20         ratePresaleStable = _rateStable;
21     }
22 }
```

Listing 14: Optimized example of Pattern 7

```
1
2  pragma solidity ^0.8.0;
3
4  contract presale {
5      address public presale_owner = 0x5B38Da6a701c568545dCfcB03FcB875f56beddC4;
6
7      modifier owner {
8          require(msg.sender == presale_owner, "Requires owner");
9          _;
10     }
11
12     function updateRatePresale(uint256 _rate, uint256 _rateStable) external owner {
13         uint256 ratePresale; //listing price in wei
14         uint256 ratePresaleStable;
15
16         ratePresale = _rate;
17         ratePresaleStable = _rateStable;
18     }
19 }
```

1. Pattern explanation. This pattern occurs when the codes contain expressions that involve logical operations that could be simplified to an equivalent form with lower gas costs.

2. Example. To further illustrate this pattern, we take as an example the function *owner* of the contract *presale*, which is deployed at *0x846bB98EA9BD5e766d5FDB1a415E0cf0202D3801*. The unoptimized codes are shown in Listing 13 and the optimized version is in Listing 14. In addition, the gas consumption result is listed in Table 7. It can be observed that the if statement in the codes is redundant, where itfirsting assigns *isOwner* to false, changes it to true under certain conditions, and finally places *isOwner* as the condition of a require statement. Instead, it would be both more readable and less gas-costly if all those operations could be condensed into one line as *require(msg.sender == presale_owner, "Requires owner");* This way, we get to save the logical comparisons.

0.8 Pattern 8. Replacing item-by-item iterated arrays by a map.

Table 8: Gas consumption table for pattern 8.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	630622	475076	**24.665%**	96842	93068	**3.8970%**
Execution cost	536968	392430	**26.917%**	99428	94711	**4.7441%**

Listing 15: Unptimized example of Pattern 8

```
1
2  pragma solidity ^0.8.0;
3
4  contract DigiMonkzStaking {
5
6      mapping(address => uint16[]) public gen1StakedArray;
7      mapping(uint16 => bool) public isGen1Staked;
8
9      function gen1IndividualStake(uint16 _tokenId) private {
10         require(isGen1Staked[_tokenId] == false);
11         gen1StakedArray[msg.sender].push(_tokenId);
12         isGen1Staked[_tokenId] = true;
13         // emit Stake(_tokenId);
14     }
15
16
17     function gen1Stake(uint16[] memory _tokenIds) private returns (bool) {
18         uint256 tokenLen = _tokenIds.length;
19         for (uint256 i = 0; i < tokenLen; i++) {
20             gen1IndividualStake(_tokenIds[i]);
21         }
22         return true;
23     }
24
25     function gen1IndividualUnstake(uint16 _tokenId) private {
26
27         uint256 len = gen1StakedArray[msg.sender].length;
28         require(len != 0);
29
30         uint256 idx = len;
31         for (uint16 i = 0; i < len; i++) {
32             if (gen1StakedArray[msg.sender][i] == _tokenId) {
33                 idx = i;
34             }
35         }
36         require(idx != len);
37
38         // uint256 stakedTime = gen1InfoPerStaker[msg.sender][idx].stakedAt;
39         if (idx != len - 1) {
40             gen1StakedArray[msg.sender][idx] = gen1StakedArray[msg.sender][
41                 len - 1
42             ];
43         }
44
45         gen1StakedArray[msg.sender].pop();
46         isGen1Staked[_tokenId] = false;
47
48         // emit Unstake(_tokenId, stakedTime, block.timestamp);
49     }
50
51     function gen1Unstake(uint16[] memory _tokenIds) external returns (bool) {
52         // for testing purposes, we first load the token ids
53         gen1Stake(_tokenIds);
54         uint256 tokenLen = _tokenIds.length;
55         for (uint256 i = 0; i < tokenLen; i++) {
56             gen1IndividualUnstake(_tokenIds[i]);
57         }
58         return true;
59     }
60 }
```

Listing 16: Optimized example of Pattern 8

```
1
2  pragma solidity ^0.8.0;
3
4  contract DigiMonkzStaking {
5
6      mapping(address => mapping(uint16 => bool)) public gen1StakedArray;
7      mapping(uint16 => bool) public isGen1Staked;
8
9      function gen1IndividualStake(uint16 _tokenId) private {
10         require(isGen1Staked[_tokenId] == false);
11         gen1StakedArray[msg.sender][_tokenId] = true;
12         isGen1Staked[_tokenId] = true;
```

```
13          // emit Stake(_tokenId);
14      }
15
16      function gen1Stake(uint16[] memory _tokenIds) private returns (bool) {
17          uint256 tokenLen = _tokenIds.length;
18          for (uint256 i = 0; i < tokenLen; i++) {
19              gen1IndividualStake(_tokenIds[i]);
20          }
21          return true;
22      }
23
24      function gen1IndividualUnstake(uint16 _tokenId) private {
25          require (gen1StakedArray[msg.sender][_tokenId] == true);
26
27          gen1StakedArray[msg.sender][_tokenId] = false;
28          isGen1Staked[_tokenId] = false;
29
30          // emit Unstake(_tokenId, stakedTime, block.timestamp);
31      }
32
33      function gen1Unstake(uint16[] memory _tokenIds) external returns (bool) {
34          // for testing purposes, we first load the token ids
35          gen1Stake(_tokenIds);
36          uint256 tokenLen = _tokenIds.length;
37          for (uint256 i = 0; i < tokenLen; i++) {
38              gen1IndividualUnstake(_tokenIds[i]);
39          }
40          return true;
41      }
42  }
```

1. Pattern explanation. This pattern occurs when there is an array that often gets iterated to extract particular elements (i.e. O(N) to find a result), while the same effect could be achieved by implementing the data structure instead as a map (i.e. O(1) to find a result). Arrays are great for storing ordered data but can be gas-inefficient when used for lookups and deletions.

2. Example. To further illustrate this pattern, we take as an example the function *gen1IndividualUnstake* of the contract *DigiMonkzStaking*, which is deployed at *0x077B1BB5Aa45A907866cd8338592b6B2080EF747*. The unoptimized codes are shown in Listing 15 and the optimized version is in Listing 16. In addition, the gas consumption result is listed in Table 8. In particular, in the optimized version, we get rid of the for loop and instead find the idx variable using a map, which is much more gas-friendly.

0.9 Pattern 9. Repeated security checks across function calls.

Table 9: Gas consumption table for pattern 9.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	428902	381781	**10.986%**	26312	26242	**0.2660%**
Execution cost	350386	306143	**12.626%**	4384	4314	**1.5967%**

Listing 17: Unptimized example of Pattern 9

```
1
2  pragma solidity ^0.8.0;
3
4  contract OperaBaseTokenTaxed{
5      mapping(address => mapping(address => uint256)) _allowances;
6      uint256 public _totalSupply;
7      mapping(address => uint256) _balances;
8
9      function transferFrom(
10         address sender,
11         address recipient,
12         uint256 amount
13     ) external returns (bool) {
14         require(sender != address(0), "ERC20: transfer from the zero address");
15         require(recipient != address(0), "ERC20: transfer to the zero address");
16
17         return _transferFrom(sender, recipient, amount);
18     }
19
20     function _transferFrom(
21         address sender,
22         address recipient,
23         uint256 amount
24     ) internal returns (bool) {
25         require(sender != address(0), "ERC20: transfer from the zero address");
26         require(recipient != address(0), "ERC20: transfer to the zero address");
27
28         _balances[sender] = _balances[sender] - amount;
29
30         _balances[recipient] = _balances[recipient] + amount;
31
32         return true;
33     }
34 }
```

Listing 18: Optimized example of Pattern 9

```
1
2  pragma solidity ^0.8.0;
3
4  contract OperaBaseTokenTaxed{
5      mapping(address => mapping(address => uint256)) _allowances;
6      uint256 public _totalSupply;
7      mapping(address => uint256) _balances;
8
9      function transferFrom(
10         address sender,
11         address recipient,
12         uint256 amount
13     ) external returns (bool) {
14         return _transferFrom(sender, recipient, amount);
15     }
16
17     function _transferFrom(
18         address sender,
19         address recipient,
20         uint256 amount
21     ) internal returns (bool) {
22         require(sender != address(0), "ERC20: transfer from the zero address");
23         require(recipient != address(0), "ERC20: transfer to the zero address");
24
25         _balances[sender] = _balances[sender] - amount;
26
27         _balances[recipient] = _balances[recipient] + amount;
28
29         return true;
30     }
31 }
```

1. Pattern explanation. This pattern occurs when in function calls, the caller first performs some kind of a security check and then immediately followed by a call to another function in which the same set of security checks are performed. This constitutes a repeated security check upon entry, and the caller's security check could be removed.

2. Example. To further illustrate this pattern, we take as an example the function *transferFrom* of the contract *OperaBaseTokenTaxed*, which is deployed at *0x0586638503CCaA365cD8a1338f3b84C54BAe65B3*. The unoptimized codes are shown in Listing 17 and the optimized version is in Listing 18. In addition, the gas consumption result is listed in Table 9.

In the unoptimized contract, the *transferFrom* function conducts two security checks, represented by "require" statements. These checks are then repeated in the immediately following invocation of the *_transferFrom* function, unnecessarily resulting in redundancy. To optimize this, we eliminated the checks within the transferFrom function.

It's important to note that we didn't remove the checks from the *_transferFrom* function, as we can't be certain all callers of this function will consistently perform the necessary security checks. However, we have confidence in removing checks from the *transferFrom* function given that it consistently calls *_transferFrom*.

0.10 Pattern 10. Unnecessarily introducing variables.

Table 10: Gas consumption table for pattern 10.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	287979	276947	**3.8308%**	24966	24852	**0.4566%**
Execution cost	218263	208051	**4.6787%**	1790	1676	**6.3687%**

Listing 19: Unptimized example of Pattern 10

```

pragma solidity ^0.8.0;

contract Donate3  {
    function _transferToken(
        address token,
        address from,
        uint256 amountInDesired,
        address rAddress,
        bytes calldata merkleProof
    ) internal returns (uint256 amountOut) {
        return 1;
    }

    function donateERC20(
        address _token,
        string calldata _tokenSymbol,
        uint256 _amountInDesired,
        address _to,
        bytes calldata _message,
        bytes calldata _merkleProof
    ) external {
        address from = msg.sender;
        string calldata symbol = _tokenSymbol;
        bytes calldata message = _message;
        address token = _token;
        bytes calldata merkleProof = _merkleProof;
        uint256 amountInDesired = _amountInDesired;

        address to = _to;
        require(from != to, "The donor address is equal to receive");

        uint256 amountOut = _transferToken(
            token,
            from,
            amountInDesired,
            to,
            merkleProof
        );
    }
}
```

Listing 20: Optimized example of Pattern 10

```

pragma solidity ^0.8.0;

contract Donate3  {
    function _transferToken(
        address token,
        address from,
        uint256 amountInDesired,
        address rAddress,
        bytes calldata merkleProof
    ) internal returns (uint256 amountOut) {
        return 1;
    }

    function donateERC20(
        address _token,
        string calldata _tokenSymbol,
        uint256 _amountInDesired,
        address _to,
        bytes calldata _message,
        bytes calldata _merkleProof
    ) external {
        address from = msg.sender;
        require(from != _to, "The donor address is equal to receive");

        uint256 amountOut = _transferToken(
            _token,
            from,
            _amountInDesired,
            _to,
            _merkleProof
```

```
32            );
33        }
34    }
```

1. Pattern explanation. This pattern occurs when codes introduce new but unnecessarily derived variables, where just using the original one would have the same effect. Such new variables could be removed to save gas.

2. Example. To further illustrate this pattern, we take as an example the function *donateERC20* of the contract *Donate3*, which is deployed at *0x3a42ddc676f6854730151750f3dbd0ebfe3c6cd3*. The unoptimized codes are shown in Listing 19 and the optimized version is in Listing 20. In addition, the gas consumption result is listed in Table 10. In particular, in the unoptimized contract, it can be observed that multiple variables like symbol, message, token, merkleProof, and amountInDesired are just straightforward duplicates of their corresponding input variables. This extra step is not necessary as defining new variables consumes gas, and we remove this part in the optimized codes.

0.11 Pattern 11. Unnecessary overflow/underflow validation since Solidity 0.

Table 11: Gas consumption table for pattern 11.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	273423	246758	**9.7522%**	37597	36997	**1.5958%**
Execution cost	204845	179826	**12.213%**	13553	12953	**4.4270%**

Listing 21: Unptimized example of Pattern 11

```
1
2  pragma solidity ^0.8.0;
3
4  contract KSElasticLMV2 {
5      event WithdrawUnusedRewards(
6          address token,
7          uint256 amount,
8          address receiver
9      );
10
11     function withdrawUnusedRewards(
12         address[] calldata tokens,
13         uint256[] calldata amounts
14     ) external {
15         uint256 rewardTokenLength = tokens.length;
16         for (uint256 i; i < rewardTokenLength; ) {
17             emit WithdrawUnusedRewards(tokens[i], amounts[i], msg.sender);
18             ++i;
19         }
20     }
21 }
```

Listing 22: Optimized example of Pattern 11

```
1
2  pragma solidity ^0.8.0;
3
4  contract KSElasticLMV2 {
5      event WithdrawUnusedRewards(
6          address token,
7          uint256 amount,
8          address receiver
9      );
10
11     function withdrawUnusedRewards(
12         address[] calldata tokens,
13         uint256[] calldata amounts
14     ) external {
15         uint256 rewardTokenLength = tokens.length;
16         for (uint256 i; i < rewardTokenLength; ) {
17             emit WithdrawUnusedRewards(tokens[i], amounts[i], msg.sender);
18
19             unchecked {
20                 ++i;
21             }
22         }
23     }
24 }
```

1. Pattern explanation. Since Solidity 0.8.0, over- and unver-flow checks are inherently integrated and using safemath or manual validation becomes unnecessary. This means that if we are confident that our usage of the variable will not cause over- or under-flow for certain code lines, then we should just use the "unchecked" keyword on the corresponding lines to save the inherently integrated checks.

2. Example. To further illustrate this pattern, we take as an example the function *withdrawUnusedRewards* of the contract *KSElasticLMV2*, which is deployed at *0x3D6AfE2fB73fFEd2E3dD00c501A174554e147a43*. The unoptimized codes are shown in Listing 21 and the optimized version is in Listing 22. In addition, the gas consumption result is listed in Table 11. Note that in this example, we use the original contract as the optimized codes and a modified contract (i.e. with the "unchecked" keyword removed) as the unoptimized codes. In particular, The gas is saved because in the optimized version, there are no longer repeated checks for overflow and underflow upon each iteration of the loop.

0.12 Pattern 12. Redundant memory array initialization.

Table 12: Gas consumption table for pattern 12.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	153465	100093	**34.777%**	21755	21463	**1.3422%**
Execution cost	93541	43293	**53.717%**	691	399	**42.257%**

Listing 23: Unptimized example of Pattern 12

```
1
2 pragma solidity ^0.8.17;
3
4 contract AaveV2Strategy {
5     function assetRatio() public returns (uint256) {
6         uint256[] memory _assetRatio = new uint256[](3);
7         _assetRatio[0] = 1;
8         _assetRatio[1] = 2;
9         _assetRatio[2] = 3;
10        return 1;
11    }
12 }
```

Listing 24: Optimized example of Pattern 12

```
1
2 pragma solidity ^0.8.17;
3
4 contract AaveV2Strategy {
5     function assetRatio() public returns (uint256) {
6         uint256[3] memory _assetRatio = [uint256(1),2,3];
7         return 1;
8     }
9 }
```

1. Pattern explanation. This pattern occurs when new memory arrays are initialized with a fixed size and then manually populated with values. A more gas-efficient approach is to initialize the array with populated values in one step (e.g. direct initialization like [1,2]).

2. Example. To further illustrate this pattern, we take as an example the function *assetRatio* of the contract *AaveV2Strategy*, which is deployed at *0x331c27d9daf6d8f6a2dbf3c16b5c5733da1b4431*. The unoptimized codes are shown in Listing 23 and the optimized version is in Listing 24. In addition, the gas consumption result is listed in Table 12. It can be observed that the optimized version initializes and populates the fixed-size array in just one step.

0.13 Pattern 13. Placement of require statements.

Table 13: Gas consumption table for pattern 13.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	431521	431533	**-0.002%**	31680	30834	**2.6704%**
Execution cost	352233	352233	**0.0%**	4444	3598	**19.036%**

Listing 25: Unptimized example of Pattern 13

```
1
2  pragma solidity ^0.8.0;
3
4  contract DoughImplementationM1 {
5      mapping (address => bool) internal _auth;
6      address internal immutable doughIndex = address(0x0);
7
8      function isConnectors(string[] calldata) internal returns (bool) {
9          return false;
10     }
11
12     function cast(
13         string[] calldata _targetNames,
14         bytes[] calldata _datas,
15         address _origin
16     )
17     public
18     payable
19     returns (bytes32) // Dummy return to fix doughIndex buildWithCast function
20     {
21         uint256 _length = _targetNames.length;
22         require(_auth[msg.sender] || msg.sender != doughIndex, "1: permission-denied");
23         require(_length != 0, "1: length-invalid");
24         require(_length == _datas.length , "1: array-length-invalid");
25
26         string[] memory eventNames = new string[](_length);
27         bytes[] memory eventParams = new bytes[](_length);
28
29         bool isOk = isConnectors(_targetNames);
30
31         require(isOk, "1: not-connector");
32
33     }
34 }
```

Listing 26: Optimized example of Pattern 13

```
1
2  pragma solidity ^0.8.0;
3
4  contract DoughImplementationM1 {
5      mapping (address => bool) internal _auth;
6      address internal immutable doughIndex = address(0x0);
7
8      function isConnectors(string[] calldata) internal returns (bool) {
9          return false;
10     }
11
12     function cast(
13         string[] calldata _targetNames,
14         bytes[] calldata _datas,
15         address _origin
16     )
17     public
18     payable
19     returns (bytes32) // Dummy return to fix doughIndex buildWithCast function
20     {
21         uint256 _length = _targetNames.length;
22         require(_auth[msg.sender] || msg.sender != doughIndex, "1: permission-denied");
23         require(_length != 0, "1: length-invalid");
24         require(_length == _datas.length , "1: array-length-invalid");
25
26         bool isOk = isConnectors(_targetNames);
27         require(isOk, "1: not-connector");
28
29         string[] memory eventNames = new string[](_length);
30         bytes[] memory eventParams = new bytes[](_length);
31     }
32 }
```

1. Pattern explanation. If no dependency is required, we should put the require statements as early as possible, such that upon errors, we do not make unnecessary executions of unrelated lines.

This is because the execution will revert anyways upon executing the failed require statement, then there is no need to execute unrelated lines.

2. Example. To further illustrate this pattern, we take as an example the function of the contract , which is deployed at . The unoptimized codes are shown in Listing 25 and the optimized version is in Listing 26. In addition, the gas consumption result is listed in Table 13. Note that in the unoptimized version, an extra set of initializations of 2 arrays are defined at lines 26 and 27. Then if the next require statement at line 31 fails, the gas paid for the initialization of the arrays will be wasted.

0.14 Pattern 14. Avoid no-op writes to state variables.

Table 14: Gas consumption table for pattern 14.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	152253	153969	**-1.127%**	24065	23974	**0.3781%**
Execution cost	92541	94141	**-1.728%**	3001	2910	**3.0323%**

Listing 27: Unptimized example of Pattern 14

```
1
2  pragma solidity ^0.8.0;
3
4  contract IdleStrategy  {
5      uint256 private _lastIdleTokenPrice;
6
7      function _calculateYieldPercentage(uint256 inVal) internal returns (uint256) {
8          return inVal % 2 + inVal;
9      }
10
11     function tokenPriceWithFee(address inVal) internal returns (uint256) {
12         return 0;
13     }
14
15     function _getYieldPercentage() public returns (uint256 baseYieldPercentage) {
16         uint256 currentIdleTokenPrice = tokenPriceWithFee(address(this));
17         uint256 cachedVal = _lastIdleTokenPrice;
18
19         baseYieldPercentage = _calculateYieldPercentage(cachedVal);
20
21         _lastIdleTokenPrice = currentIdleTokenPrice;
22     }
23 }
```

Listing 28: Optimized example of Pattern 14

```
1
2  pragma solidity ^0.8.0;
3
4  contract IdleStrategy  {
5      uint256 private _lastIdleTokenPrice;
6
7      function _calculateYieldPercentage(uint256 inVal) internal returns (uint256) {
8          return inVal % 2 + inVal;
9      }
10
11     function tokenPriceWithFee(address inVal) internal returns (uint256) {
12         return 0;
13     }
14
15     function _getYieldPercentage() public returns (uint256 baseYieldPercentage) {
16         uint256 currentIdleTokenPrice = tokenPriceWithFee(address(this));
17         uint256 cachedVal = _lastIdleTokenPrice;
18
19         baseYieldPercentage = _calculateYieldPercentage(cachedVal);
20
21         if (currentIdleTokenPrice != cachedVal) {
22             _lastIdleTokenPrice = currentIdleTokenPrice;
23         }
24     }
25 }
```

1. Pattern explanation. This pattern occurs when a variable gets rewritten by a value that is the same as the existing value. This is a no-op and is especially expensive for storage variables.
2. Example. To further illustrate this pattern, we take as an example the function *_getYieldPercentage* of the contract *IdleStrategy*, which is deployed at *0x1892038be4bd3968f4a8574593032d61c88dcacb*. The unoptimized codes are shown in Listing 27 and the optimized version is in Listing 28. In addition, the gas consumption result is listed in Table 14. In particular, the unoptimized contract unconditionally writes to a state variable, where if the new value is the same as the old one, gas would be wasted.

0.15 Pattern 15. Reordering conditional checks for short-circuiting.

Table 15: Gas consumption table for pattern 15.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	353980	353980	**0.0%**	23078	22947	**0.5676%**
Execution cost	280518	280518	**0.0%**	1150	1019	**11.391%**

Listing 29: Unptimized example of Pattern 15

```
1
2  pragma solidity ^0.8.0;
3
4  contract DEVGPT {
5
6      function owner() internal returns (address) {
7          return address(0x0);
8      }
9
10     function balanceOf(address) internal returns (uint256) {
11         return 100;
12     }
13
14     function _transfer(
15         address from,
16         address to,
17         uint256 amount
18     ) public {
19         require(from != address(0), "ERC20: transfer from the zero address");
20         require(to != address(0), "ERC20: transfer to the zero address");
21         require(amount > 0, "Transfer amount must be greater than zero");
22
23         if (from != owner() && to != owner() && from != address(this) && to != 0
               x2f8fD77D037C0778E98fF160168995CD14634eaE) {
24             uint256 contractTokenBalance = balanceOf(address(this));
25         }
26     }
27 }
```

Listing 30: Optimized example of Pattern 15

```
1
2  pragma solidity ^0.8.0;
3
4  contract DEVGPT {
5
6      function owner() internal returns (address) {
7          return address(0x0);
8      }
9
10     function balanceOf(address) internal returns (uint256) {
11         return 100;
12     }
13
14     function _transfer(
15         address from,
16         address to,
17         uint256 amount
18     ) public {
19         require(from != address(0), "ERC20: transfer from the zero address");
20         require(to != address(0), "ERC20: transfer to the zero address");
21         require(amount > 0, "Transfer amount must be greater than zero");
22
23         if (to != 0x2f8fD77D037C0778E98fF160168995CD14634eaE && from != owner() && to != owner() && from !=
               address(this) ) {
24             uint256 contractTokenBalance = balanceOf(address(this));
25         }
26     }
27 }
```

1. Pattern explanation. This pattern aims at utilizing the short-circuiting rule for conditional statements that are connected by "and" or "or". In particular, it suggests to restructure the conditions in a way that the scenario that have a higher chance of triggering the short-circuiting is checked first, thus avoiding unnecessary checks.

2. Example. To further illustrate this pattern, we take as an example the function *_transfer* of the contract *DEVGPT*, which is deployed at *0x2f8fD77D037C0778E98fF160168995CD14634eaE*. The unoptimized codes are shown in Listing 29 and the optimized version is in Listing 30. In addition,

the gas consumption result is listed in Table 15. In this example, we make the hypothetical assumption that the "to" address is more likely to be 0x2f8fD77D037C0778E98fF160168995CD14634eaE, and thus the condition "to != 0 x2f8fD77D037C0778E98fF160168995CD14634eaE" should be placed first, since upon its failure, the other conditional statements will not be executed.

0.16 Pattern 16. Combinable events.

Table 16: Gas consumption table for pattern 16.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	206618	178025	**13.838%**	26732	25092	**6.1349%**
Execution cost	142990	116565	**18.480%**	5668	4028	**28.934%**

Listing 31: Unptimized example of Pattern 16

```
1
2  pragma solidity >=0.7.6;
3
4  contract LEGO {
5      event logOnChain(string info);
6
7      function loggingOnChain() public {
8          emit logOnChain("pKeuLv");
9          emit logOnChain("IOpBBS");
10         emit logOnChain("pOmZqnWO");
11         uint256 e = 87;
12         uint256 p = (56 % 73) % 56;
13         uint256 rzzlcjlfc = 76 % 94;
14         uint256 joblgy = (77 % 86) % 41;
15         uint256 tfsleihel = 20 % 17;
16         if (
17             e == 56 * 71 &&
18             p == ((36 * 4) % 39) % 57 &&
19             rzzlcjlfc == 95 + 56 + 85 * 80 &&
20             joblgy == 20 % 27 &&
21             tfsleihel == (72 % 3) * 91
22         ) return;
23     }
24 }
```

Listing 32: Optimized example of Pattern 16

```
1
2  pragma solidity >=0.7.6;
3
4  contract LEGO {
5      event logOnChain(string, string, string);
6
7      function loggingOnChain() public {
8          emit logOnChain("pKeuLv", "IOpBBS", "pOmZqnWO");
9          uint256 e = 87;
10         uint256 p = (56 % 73) % 56;
11         uint256 rzzlcjlfc = 76 % 94;
12         uint256 joblgy = (77 % 86) % 41;
13         uint256 tfsleihel = 20 % 17;
14         if (
15             e == 56 * 71 &&
16             p == ((36 * 4) % 39) % 57 &&
17             rzzlcjlfc == 95 + 56 + 85 * 80 &&
18             joblgy == 20 % 27 &&
19             tfsleihel == (72 % 3) * 91
20         ) return;
21     }
22 }
```

1. Pattern explanation. Consider whether all events are absolutely necessary. If they are, consider whether they can be consolidated or whether the amount of data included can be reduced.

2. Example. To further illustrate this pattern, we take as an example the function *loggingOnChain* of the contract *LEGO*, which is deployed at *0x111ACf72AA4A1fdA8500ED9f1Ba3F2374c02a21e*. The unoptimized codes are shown in Listing 31 and the optimized version is in Listing 32. In addition, the gas consumption result is listed in Table 16. In the unoptimized example, 3 separate events are continuously emitted. To analyze their gas costs, we first note that the events at lines 7, 8, and 9 each costs 1,518 gas, totaling to 4554 gas. It is worth noting that each event has an individual charge of 375 gas for an LOG1 operation. In addition, since each event is not anonymous and no arguments are indexed (i.e. no "indexed" keywords specified), there will be only one topic, which is just the hashcode of the event signature, and thus there is a 375 gas cost for each event emission. In the optimized codes, by changing the event declaration at line 4 to accept 3 string, and combining lines 7, 8, and 9 into one event emission (i.e. *emit logOnChain("pKeuLv", "IOpBBS",*

"pOmZqnWO");), we get to reduce the gas cost down to 3,054 gas, which is a saving of 1,500 gas (32.94 %). This corresponds to saving the $750 = 2 \times 375$ gas of two LOG1 operations, as well as the $750 = 2 \times 375$ gas of two topics, since they are all combined into one line now.

0.17 Pattern 17. add constant modifier for non-changing variables.

Table 17: Gas consumption table for pattern 17.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	823085	867805	**-5.433%**	56032	50528	**9.8229%**
Execution cost	724419	768627	**-6.102%**	34092	28588	**16.144%**

Listing 33: Unptimized example of Pattern 17

```

pragma solidity ^0.8.0;

contract BBB {
    uint256 private _initialBuyTax=10;
    uint256 private _initialSellTax=30;
    uint256 private _finalBuyTax=2;
    uint256 private _finalSellTax=2;
    uint256 private _reduceBuyTaxAt=10;
    uint256 private _reduceSellTaxAt=20;
    uint256 private _preventSwapBefore=20;
    uint256 private _buyCount=0;

    uint8 private constant _decimals = 10;
    uint256 private constant _tTotal = 696969696969696 * 10**_decimals;
    string private constant _name = unicode"Benevolent Brainpower Brigade";
    string private constant _symbol = unicode"BBB";
    uint256 public _maxTxAmount = 20909090909090 * 10**_decimals;
    uint256 public _maxWalletSize = 20909090909090 * 10**_decimals;
    uint256 public _taxSwapThreshold= 6969696969696 * 10**_decimals;
    uint256 public _maxTaxSwap= 6969696969696 * 10**_decimals;

    address private uniswapV2Pair;
    bool private tradingOpen;
    bool private inSwap = false;
    bool private swapEnabled = false;

    event Transfer(address indexed from, address indexed to, uint256 value);


    function owner() internal returns (address) {
        return address(0x0);
    }

    function balanceOf(address) internal returns (uint256) {
        return 10;
    }


    function _transfer(address from, address to, uint256 amount) public {
        require(from != address(0), "ERC20: transfer from the zero address");
        require(to != address(0), "ERC20: transfer to the zero address");
        require(amount > 0, "Transfer amount must be greater than zero");
        uint256 taxAmount=0;
        if (from != owner() && to != owner()) {
            require(amount <= _maxTxAmount, "Exceeds the _maxTxAmount.");
            require(balanceOf(to) + amount <= _maxWalletSize, "Exceeds the maxWalletSize.");
            require(amount <= _maxTaxSwap, "Exceeds the _maxTaxSwap.");

            _buyCount++;

            uint256 contractTokenBalance = balanceOf(address(this));
            if (contractTokenBalance>_taxSwapThreshold) {
                uint256 contractETHBalance = address(this).balance;
            }
        }
        emit Transfer(from, to, taxAmount);
    }
}
```

Listing 34: Optimized example of Pattern 17

```

pragma solidity ^0.8.0;

contract BBB {
    uint256 private _initialBuyTax=10;
    uint256 private _initialSellTax=30;
    uint256 private _finalBuyTax=2;
    uint256 private _finalSellTax=2;
    uint256 private _reduceBuyTaxAt=10;
    uint256 private _reduceSellTaxAt=20;
    uint256 private _preventSwapBefore=20;
    uint256 private _buyCount=0;

```

```
14      uint8 private constant _decimals = 10;
15      uint256 private constant _tTotal = 696969696969696 * 10**_decimals;
16      string private constant _name = unicode"Benevolent Brainpower Brigade";
17      string private constant _symbol = unicode"BBB";
18      uint256 public constant _maxTxAmount = 20909090909090 * 10**_decimals;
19      uint256 public constant _maxWalletSize = 20909090909090 * 10**_decimals;
20      uint256 public constant _taxSwapThreshold= 6969696969696 * 10**_decimals;
21      uint256 public constant _maxTaxSwap= 6969696969696 * 10**_decimals;
22
23      address private uniswapV2Pair;
24      bool private tradingOpen;
25      bool private inSwap = false;
26      bool private swapEnabled = false;
27
28      event Transfer(address indexed from, address indexed to, uint256 value);
29
30
31      function owner() internal returns (address) {
32          return address(0x0);
33      }
34
35      function balanceOf(address) internal returns (uint256) {
36          return 10;
37      }
38
39
40      function _transfer(address from, address to, uint256 amount) public {
41          require(from != address(0), "ERC20: transfer from the zero address");
42          require(to != address(0), "ERC20: transfer to the zero address");
43          require(amount > 0, "Transfer amount must be greater than zero");
44          uint256 taxAmount=0;
45          if (from != owner() && to != owner()) {
46              require(amount <= _maxTxAmount, "Exceeds the _maxTxAmount.");
47              require(balanceOf(to) + amount <= _maxWalletSize, "Exceeds the maxWalletSize.");
48              require(amount <= _maxTaxSwap, "Exceeds the _maxTaxSwap.");
49
50              _buyCount++;
51
52              uint256 contractTokenBalance = balanceOf(address(this));
53              if (contractTokenBalance>_taxSwapThreshold) {
54                  uint256 contractETHBalance = address(this).balance;
55              }
56          }
57          emit Transfer(from, to, taxAmount);
58      }
59
60  }
```

1. Pattern explanation. Solidity replaces all constant state variables by their value during compilation. This means they will not be placed in storage and thus operations on them are much cheaper than that on storage variables. As a result, if we are certain that a state variable will not change at all. then we should add a constant modifier to it.

2. Example. To further illustrate this pattern, we take as an example the function *_transfer* of the contract *BBB*, which is deployed at *0x340de5cb9b177ff1e3d00e6aa3082f979fca621e*. The unoptimized codes are shown in Listing 33 and the optimized version is in Listing 34. In addition, the gas consumption result is listed in Table 17. In particular, based on the assumption that the variables _maxTxAmount, _maxWalletSize, _taxSwapThreshold, and _maxTaxSwap are non-changing, we add a constant modifier to them in this example.

0.18 Pattern 18. Function visibility.

Table 18: Gas consumption table for pattern 18.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	418790	418790	**0.0%**	47316	27416	**42.057%**
Execution cost	339980	339980	**0.0%**	25712	5812	**77.395%**

Listing 35: Unptimized example of Pattern 18

```
1
2  pragma solidity ^0.8.0;
3
4  contract AkshunSeasonPassNft  {
5
6      string contractURI;
7      event ContractURIUpdated(string);
8      error ParamInvalid(uint8 paramPosIdx);
9
10 function updateContractURI(string memory _contractURI)
11         public
12
13     {
14         // Validate input params.
15
16         if (bytes(_contractURI).length == 0) revert ParamInvalid(0);
17
18         // Update/set state vars.
19
20         contractURI = _contractURI;
21
22         // Emit events.
23
24         emit ContractURIUpdated(_contractURI);
25     }
26
27 }
```

Listing 36: Optimized example of Pattern 18

```
1
2  pragma solidity ^0.8.0;
3
4  contract AkshunSeasonPassNft  {
5
6      string contractURI;
7      event ContractURIUpdated(string);
8      error ParamInvalid(uint8 paramPosIdx);
9
10 function updateContractURI(string memory _contractURI)
11         external
12
13     {
14         // Validate input params.
15
16         if (bytes(_contractURI).length == 0) revert ParamInvalid(0);
17
18         // Update/set state vars.
19
20         contractURI = _contractURI;
21
22         // Emit events.
23
24         emit ContractURIUpdated(_contractURI);
25     }
26
27 }
```

1. Pattern explanation. This pattern notes the fact that functions of different visibility (i.e. public v.s. external) consume different amounts of gas, where public functions cost more gas. This is because for public functions, the input parameters are copied into memory automatically, which costs gas, while external functions could directly read from calldata. Therefore, if we are certain that the function will not be called internally, we should declare it as external instead of public.
2. Example. To further illustrate this pattern, we take as an example the function *updateContractURI* of the contract *AkshunSeasonPassNft*, which is deployed at *0x7e9F2D2583FEF83aF0dDA74E457B6320228B20dE*. The unoptimized codes are shown in Listing 35 and the optimized version is in Listing 36. In addition, the gas consumption result is listed in Table 18. In this example, we make the assumption

that the "updateContractURI" function will not be called internally, and change its visibility to external. This contributes to a huge amount of saved gas.

0.19 Pattern 19. Dead codes.

Table 19: Gas consumption table for pattern 19.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	158393	149733	**5.4674%**	22351	22073	**1.2437%**
Execution cost	97947	89941	**8.1738%**	1147	869	**24.237%**

Listing 37: Unptimized example of Pattern 19

```
1
2 pragma solidity ^0.8.0;
3
4 contract ExampleContract {
5     function exampleFunction(uint x) public returns (uint256) {
6         if ( x > 5) {
7             if ( x*x < 20) {
8                 return 5 * x;
9             }
10            else {
11                return 4 * x;
12            }
13        }
14        else {
15            return x;
16        }
17    }
18
19 }
```

Listing 38: Optimized example of Pattern 19

```
1
2 pragma solidity ^0.8.0;
3
4 contract ExampleContract {
5     function exampleFunction(uint x) public returns (uint256) {
6         if ( x > 5) {
7             return 4 * x;
8         }
9         else {
10            return x;
11        }
12    }
13
14 }
```

1. Pattern explanation. Any code that is not used or cannot be reached during execution is wasteful and consumes unnecessary gas. Therefore, they should be removed.

2. Example. To further illustrate this pattern, we take the example from an existing paper [2]. The unoptimized codes are shown in Listing 37 and the optimized version is in Listing 38. In addition, the gas consumption result is listed in Table 19. It can be observed from the codes that once we enter the branch where "x > 5," it is never possible for "x*x < 20" to be true. Therefore, we could remove the corresponding branch as these are dead codes.

0.20 Pattern 20. Using revert instead of require for error handling.

Table 20: Gas consumption table for pattern 20.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	261062	210431	**19.394%**	22312	22024	**1.2907%**
Execution cost	197220	150171	**23.856%**	980	692	**29.387%**

Listing 39: Unptimized example of Pattern 20

```
1
2  pragma solidity ^0.8.0;
3
4  contract DOLLARAI {
5      uint256 private _redisFeeOnBuy = 0;
6      uint256 private _taxFeeOnBuy = 30;
7      uint256 private _redisFeeOnSell = 0;
8      uint256 private _taxFeeOnSell = 45;
9
10     function setFee(uint256 taxFeeOnBuy, uint256 taxFeeOnSell) public {
11         require(taxFeeOnBuy >= 0 && taxFeeOnBuy <= 99, "Buy tax must be between 0% and 99%");
12         require(taxFeeOnSell >= 0 && taxFeeOnSell <= 99, "Sell tax must be between 0% and 99%");
13
14         _taxFeeOnBuy = taxFeeOnBuy;
15         _taxFeeOnSell = taxFeeOnSell;
16     }
17 }
```

Listing 40: Optimized example of Pattern 20

```
1
2  pragma solidity ^0.8.0;
3
4  contract DOLLARAI {
5      uint256 private _redisFeeOnBuy = 0;
6      uint256 private _taxFeeOnBuy = 30;
7      uint256 private _redisFeeOnSell = 0;
8      uint256 private _taxFeeOnSell = 45;
9
10     error InvalidRangeOfInput();
11
12     function setFee(uint256 taxFeeOnBuy, uint256 taxFeeOnSell) public {
13         if (taxFeeOnBuy < 0) revert InvalidRangeOfInput();
14         if (taxFeeOnBuy > 99) revert InvalidRangeOfInput();
15         if (taxFeeOnSell < 0) revert InvalidRangeOfInput();
16         if (taxFeeOnSell > 99) revert InvalidRangeOfInput();
17
18         _taxFeeOnBuy = taxFeeOnBuy;
19         _taxFeeOnSell = taxFeeOnSell;
20     }
21 }
```

1. Pattern explanation. As a new feture from Solidity 0.8.4, "revert" costs less gas for both deployment and running when applied on custom errors. This means that if possible, we should use "revert" with custom errors instead of "require".

2. Example. To further illustrate this pattern, we take as an example the function *setFee* of the contract *DOLLARAI*, which is deployed at *0xfC31f0457DaB6A52432a033f13111981f464b74a*. The unoptimized codes are shown in Listing 39 and the optimized version is in Listing 40. In addition, the gas consumption result is listed in Table 20. In particular, the gas is saved because we have replace the "require" statements with "revert" with custom errors. Since "require" statements internally uses "revert" statements upon failure.

0.21 Pattern 21. Minimization of event message string.

Table 21: Gas consumption table for pattern 21.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	178025	137837	**22.574%**	25092	23152	**7.7315%**
Execution cost	116565	78529	**32.630%**	4028	2088	**48.162%**

Listing 41: Unptimized example of Pattern 21

```
1
2  pragma solidity >=0.7.6;
3
4  contract LEGO {
5      event logOnChain(string, string,string);
6
7      function loggingOnChain() public {
8        emit logOnChain("pKeuLv", "IOpBBS", "pOmZqnWO");
9        uint256 e = 87;
10       uint256 p = 56 % 73 % 56;
11       uint256 rzzlcjlfc = 76 % 94;
12       uint256 joblgy = 77 % 86 % 41;
13       uint256 tfsleihel = 20 % 17;
14       if (e == 56 * 71 && p == 36 * 4 % 39 % 57 && rzzlcjlfc == 95 + 56 + 85 * 80 && joblgy == 20 % 27 &&
             tfsleihel == 72 % 3 * 91) return;
15     }
16 }
```

Listing 42: Optimized example of Pattern 21

```
1
2  pragma solidity >=0.7.6;
3
4  contract LEGO {
5      event logOnChain(string);
6
7      function loggingOnChain() public {
8        emit logOnChain("pKeuLv & IOpBBS & pOmZqnWO");
9        uint256 e = 87;
10       uint256 p = 56 % 73 % 56;
11       uint256 rzzlcjlfc = 76 % 94;
12       uint256 joblgy = 77 % 86 % 41;
13       uint256 tfsleihel = 20 % 17;
14       if (e == 56 * 71 && p == 36 * 4 % 39 % 57 && rzzlcjlfc == 95 + 56 + 85 * 80 && joblgy == 20 % 27 &&
             tfsleihel == 72 % 3 * 91) return;
15     }
16 }
```

1. Pattern explanation. The size of input data for the emission of events costs gas, where each byte incurs a cost of 8 gas. Therefore, we should be careful with this and consider minimizing the amount of data to include in a event message.

2. Example. To further illustrate this pattern, we take as an example the function *loggingOnChain* of the contract *LEGO*, which is deployed at *0x111ACf72AA4A1fdA8500ED9f1Ba3F2374c02a21e*. The unoptimized codes are shown in Listing 41 and the optimized version is in Listing 42. In addition, the gas consumption result is listed in Table 21. In particular, the gas is saved because we have reduced the input data size from 3 strings into only one.

0.22 Pattern 22. Replacing MUL/DIV of powers of 2 by SHL/SHR.

Table 22: Gas consumption table for pattern 22.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	172617	144589	**16.237%**	21847	21604	**1.1122%**
Execution cost	111759	85335	**23.643%**	783	540	**31.034%**

Listing 43: Unptimized example of Pattern 22

```
1
2 pragma solidity ^0.8.0;
3
4 contract PancakeChainlinkOracle {
5     uint256 public constant Q96 = 2 ** 96;
6     uint256 public constant s = 2 ** 96;
7
8     function latestAnswer() public returns (uint) {
9         uint256 priceX96 = 1;
10        return Q96 * s / priceX96;
11    }
12 }
```

Listing 44: Optimized example of Pattern 22

```
1
2 pragma solidity ^0.8.0;
3
4 contract PancakeChainlinkOracle {
5     uint256 public constant Q96 = 2 ** 96;
6     uint256 public constant s = 96;
7
8     function latestAnswer() public returns (uint) {
9         uint256 priceX96 = 1;
10        return (Q96 << s) / priceX96;
11    }
12 }
```

1. Pattern explanation. This pattern saves gas by specifying that a MUL or DIV opcode costs 5 gas, while the corresponding SHL and SHR only costs 3 gas. This means when multiplying or dividing by powers of 2, it is more gas-efficient to instead use bit shifts.

2. Example. To further illustrate this pattern, we take as an example the function *latestAnswer* of the contract *PancakeChainlinkOracle*, which is deployed at *0x708d6c06df93fafd08f64f20564cebcc70dee12e*. The unoptimized codes are shown in Listing 43 and the optimized version is in Listing 44. In addition, the gas consumption result is listed in Table 22. In particular, the gas saving in this example not only came from setting MUL to SHL, but also in that when MUL is used, more preparatory work in the form of a large chunk of bytecodes is observed.

0.23 Pattern 23. Struct variable reordering.

Table 23: Gas consumption table for pattern 23.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	276923	276959	**-0.013%**	91601	89701	**2.0742%**
Execution cost	207451	207451	**0.0%**	70537	68637	**2.6936%**

Listing 45: Unptimized example of Pattern 23

```
1
2  pragma solidity ^0.8.0;
3
4  contract ExampleContract {
5
6      struct Struct {
7          uint mem1 ;
8          address mem2 ;
9          uint mem3 ;
10         bool mem4 ;
11     }
12
13     Struct public data ;
14
15     function setData () internal {
16         data = Struct (1 , address (0) , 1 , true ) ;
17     }
18
19     function getData () internal returns (Struct memory) {
20         return data ;
21     }
22
23     function exampleFunction() public returns  (Struct memory) {
24         setData();
25         return getData();
26     }
27 }
```

Listing 46: Optimized example of Pattern 23

```
1
2  pragma solidity ^0.8.0;
3
4  contract ExampleContract {
5
6      struct Struct {
7          uint mem1 ;
8          address mem2 ;
9          bool mem4 ;
10         uint mem3 ;
11     }
12
13     Struct public data ;
14
15     function setData () internal {
16         data = Struct (1 , address (0) , true , 1 ) ;
17     }
18
19     function getData () internal returns (Struct memory) {
20         return data ;
21     }
22
23     function exampleFunction() public returns  (Struct memory) {
24         setData();
25         return getData();
26     }
27 }
```

1. Pattern explanation. By reordering the variables inside a struct, we could arrange them arranged to form a more compact layout such that they occupy less storage space and thus both storing and accesses to them would save gas.

2. Example. To further illustrate this pattern, we take the example from an existing paper [4]. The unoptimized codes are shown in Listing 45 and the optimized version is in Listing 46. In addition, the gas consumption result is listed in Table 23. In particular, in the unoptimized contract, 4 storage slots are taken, with each member variable taking one slot. On the other hand, in the optimized version, by exchanging the order of mem3 and mem4, the variables mem2 and mem4 get packed

into one storage slot since mem2 only takes 20 bytes and mem4 only 1 byte. This largely saves storage space and thus the gas required to access the state variables.

0.24 Pattern 24. Loop invariant codes.

Table 24: Gas consumption table for pattern 24.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	215033	216353	**-0.613%**	101534	63135	**37.818%**
Execution cost	153571	154771	**-0.781%**	80330	41931	**47.801%**

Listing 47: Unptimized example of Pattern 24

```
1
2 pragma solidity ^0.8.0;
3
4 contract ExampleContract  {
5     uint x = 1;
6     uint y = 2;
7
8     function exampleFunction(uint k) public returns (uint256 amountOut) {
9         uint sum = 0;
10        for ( uint i = 1 ; i <= k ; i++) {
11            sum = sum + x + y;
12        }
13        return sum;
14    }
15 }
```

Listing 48: Optimized example of Pattern 24

```
1
2 pragma solidity ^0.8.0;
3
4 contract ExampleContract  {
5     uint x = 1;
6     uint y = 2;
7
8     function exampleFunction(uint k) public returns (uint256 amountOut) {
9         uint sum = 0;
10        uint s = x + y;
11        for ( uint i = 1 ; i <= k ; i++) {
12            sum = sum + s;
13        }
14        return sum;
15    }
16 }
```

1. Pattern explanation. This pattern occurs when some lines of codes, which would produce the same output upon each execution, is carried out in each iteration of a loop. This wastes gas because these lines of codes could be moved outside the loop to be executed by just once.

2. Example. To further illustrate this pattern, we take the example from an existing paper [2]. The unoptimized codes are shown in Listing 47 and the optimized version is in Listing 48. In addition, the gas consumption result is listed in Table 24. In particular, the operation "x + y" would produce the same result every time the loop executes, which wastes gas. Instead, in the optimized version, we move the computation ourside the loop and store the result in an intermediate variable "s" and thus avoid the repetitive computations.

0.25 Pattern 25. Avoid expensive operations inside loops.

Table 25: Gas consumption table for pattern 25.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	170799	171435	**-0.372%**	102621	80848	**21.216%**
Execution cost	109559	110159	**-0.547%**	81417	59644	**26.742%**

Listing 49: Unptimized example of Pattern 25

```
1
2 pragma solidity ^0.8.0;
3
4 contract ExampleContract  {
5     uint sum = 0;
6     function exampleFunction(uint x) public returns (uint256 amountOut) {
7         for ( uint i = 1 ; i <= x ; i++) {
8             sum += i;
9         }
10        return sum;
11    }
12 }
```

Listing 50: Optimized example of Pattern 25

```
1
2 pragma solidity ^0.8.0;
3
4 contract ExampleContract  {
5     uint sum = 0;
6     function exampleFunction(uint x) public returns (uint256 amountOut) {
7         uint tmp = sum;
8         for ( uint i = 1 ; i <= x ; i++) {
9             tmp += i;
10        }
11        sum = tmp;
12        return tmp;
13    }
14 }
```

1. Pattern explanation. It is recommended to avoid performing gas-expensive operations inside a loop (e.g. accessing storage variables, emitting events), and if possible, restructure the codes to move them out of the loop.

2. Example. To further illustrate this pattern, we take the example from an existing paper [2]. The unoptimized codes are shown in Listing 49 and the optimized version is in Listing 50. In addition, the gas consumption result is listed in Table 25. In the optimized version, a new memory variable is introduced (i.e. tmp) to hold the intermediate computation results, and finally assigned back to sum. This largely saves gas because in the unoptimized version, during each iteration of the loop, an update to the state variable "sum" is performed, which wastes gas since repeated writes to state variables is very expensive.

0.26 Pattern 26. Struct refactoring by usage frequency.

Table 26: Gas consumption table for pattern 26.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	382703	376915	**1.5123%**	101011	100891	**0.1187%**
Execution cost	305793	300387	**1.7678%**	79807	79687	**0.1503%**

Listing 51: Unptimized example of Pattern 26

```
1
2  pragma solidity ^0.8.0;
3
4  contract CreditDAO  {
5      struct Election {
6          address maxVotes;
7          uint nextCandidateIndex;
8          mapping(address => bool) candidates;
9          mapping(address => bool) userHasVoted;
10         mapping(uint => uint) candidateVotes;
11         uint numMaxVotes;
12         uint idProcessed;
13     }
14
15     uint public nextEId;
16     mapping(uint => Election) public elections;
17
18     constructor() public {
19         nextEId ++;
20     }
21
22     function submitForElection() public {
23         elections[nextEId - 1].nextCandidateIndex ++;
24         elections[nextEId - 1].candidates[msg.sender] = true;
25     }
26
27     function vote(uint candidateId) public {
28         elections[nextEId - 1].candidateVotes[candidateId] += 1;
29         elections[nextEId - 1].userHasVoted[msg.sender] = true;
30     }
31
32     function finishElections(uint _iterations) public {
33         uint currentVotes;
34         Election storage election = elections[nextEId - 1];
35         uint nextId = election.idProcessed;
36
37         for (uint cnt = 0; cnt < _iterations; cnt++) {
38             currentVotes = election.candidateVotes[nextId];
39             if (currentVotes > election.numMaxVotes) {
40                 election.numMaxVotes = currentVotes;
41             }
42             nextId++;
43         }
44         election.idProcessed = nextId;
45     }
46 }
```

Listing 52: Optimized example of Pattern 26

```
1
2  pragma solidity ^0.8.0;
3
4  contract CreditDAO  {
5      struct Election {
6          address maxVotes;
7          uint nextCandidateIndex;
8          mapping(address => bool) candidates;
9          mapping(address => bool) userHasVoted;
10         mapping(uint => uint) candidateVotes;
11
12         uint idProcessed;
13     }
14
15     uint numMaxVotes;
16     uint public nextEId;
17     mapping(uint => Election) public elections;
18
19     constructor() public {
20         nextEId ++;
21     }
22
23     function submitForElection() public {
24         elections[nextEId - 1].nextCandidateIndex ++;
25         elections[nextEId - 1].candidates[msg.sender] = true;
26     }
```

```
27
28      function vote(uint candidateId) public {
29          elections[nextEId - 1].candidateVotes[candidateId] += 1;
30          elections[nextEId - 1].userHasVoted[msg.sender] = true;
31      }
32
33      function finishElections(uint _iterations) public {
34          uint currentVotes;
35          Election storage election = elections[nextEId - 1];
36          uint nextId = election.idProcessed;
37
38          for (uint cnt = 0; cnt < _iterations; cnt++) {
39              currentVotes = election.candidateVotes[nextId];
40              if (currentVotes > numMaxVotes) {
41                  numMaxVotes = currentVotes;
42              }
43              nextId++;
44          }
45          election.idProcessed = nextId;
46      }
47  }
```

1. Pattern explanation. This pattern suggests that a struct could be restructured to extract the more frequently used member variables into standalone ones. This re-engineers access patterns and saves gas.

2. Example. To further illustrate this pattern, we take the example from an existing paper [3]. The unoptimized codes are shown in Listing 51 and the optimized version is in Listing 52. In addition, the gas consumption result is listed in Table 26. In particular, the gas is saved by extracting the more frequently accessed member variable "numMaxVotes" into a single variable.

0.27 Pattern 27. Using bytes32 for string representation.

Table 27: Gas consumption table for pattern 27.

Type of cost	$\mathscr{D}_u$	$\mathscr{D}_o$	$\mathscr{S}_{\mathscr{D}}$	$\mathscr{R}_u$	$\mathscr{R}_o$	$\mathscr{S}_{\mathscr{R}}$
Transaction cost	535430	407026	**23.981%**	33697	29939	**11.152%**
Execution cost	449628	330316	**26.535%**	11341	8191	**27.775%**

Listing 53: Unptimized example of Pattern 27

```
1
2  pragma solidity ^0.8.0;
3
4  contract VoteForLaunch {
5      uint32 public MAX_VOTING_DAYS = 10 * 24 * 3600;
6      mapping(string => bool) public reservedTicks;     // check if tick is occupied
7      event NewApplication(string tick, address applicant, uint40 expireAt, string cid, uint128 deposit);
8
9      function newVote(string memory _tick, uint40 _expireSeconds, string memory _cid) public {
10         require(_expireSeconds <= MAX_VOTING_DAYS, "more than max days to vote");
11         require(!reservedTicks[_tick], "reserved ticks can not apply");
12
13         emit NewApplication(_tick, msg.sender, uint40(block.timestamp + _expireSeconds), _cid, 10);
14     }
15 }
```

Listing 54: Optimized example of Pattern 27

```
1
2  pragma solidity ^0.8.0;
3
4  contract VoteForLaunch {
5      uint32 public MAX_VOTING_DAYS = 10 * 24 * 3600;
6      mapping(bytes32 => bool) public reservedTicks;     // check if tick is occupied
7      event NewApplication(bytes32 tick, address applicant, uint40 expireAt, bytes32 cid, uint128 deposit);
8
9      function newVote(bytes32 _tick, uint40 _expireSeconds, bytes32 _cid) public {
10         require(_expireSeconds <= MAX_VOTING_DAYS, "more than max days to vote");
11         require(!reservedTicks[_tick], "reserved ticks can not apply");
12
13         emit NewApplication(_tick, msg.sender, uint40(block.timestamp + _expireSeconds), _cid, 10);
14     }
15 }
```

1. Pattern explanation. In Solidity, bytes32 is a more efficient representation for string literals than the string type. In particular, if we are certain that the length of a string will not exceed 32 bytes, then we should use it as bytes32.

2. Example. To further illustrate this pattern, we take as an example the function *newVote* of the contract *VoteForLaunch*, which is deployed at *0xb9250f2dc0706f172F3565c11fcF9f7CFB2F27A7*. The unoptimized codes are shown in Listing 53 and the optimized version is in Listing 54. In addition, the gas consumption result is listed in Table 27. In this example, the string input types are changed into bytes32, which utilizes the better memory layout of the bytes32 variable types and thus saves gas. Note that this is based on the premise that the input size would not exceed 32 bytes, and the "string" type is still needed for inputs with arbitrary length that could be longer than 32 bytes.

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