Connect 4 Project

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Implement connect 4 game in `https://www.cbc.ca/kids/games/all/connect-4`. We use colored shapes, not just balls. To indidate a win, we replace the shapes in a trace to similar ones.

Warning:

1. This is copyrighted materials; you are not allowed to upload to the Internet.
2. Our project is different from similar products in Internet. We use shapes instead of balls.
   (a) Ask help only from teaching staff of this course.
   (b) Use solutions from ChatGPT or online tutoring websites like, but not limited to, chegg.com, violates academic integrity and is not allowed.

1 Rules

1. A Board object has several bins.
2. All bins have the same capacity, that is, the maximum number of elements a bin can hold.
3. Rules for moving are listed as follows.
   (a) At any time, number of elements in a bin cannot exceed its capacity.
   (b) The shapes in a bin are filled from bottom to top.
   (c) After adding a shape to a bin, check wether there are at least 4 consecutive shapes in one of the following directions: horizontal, vertical, diagonal, or anti-diagonal.
      i. If so, the game is finished and a winner is declared.
      ii. Otherwise, the game continues until there is no more spot to add a shape.
      iii. If all empty spots are filled, and there is no winner, then the game is tied.

2 Files of the Project

We use Object-oriented Programming approach.

1. Create directory `connect4` to hold codes of the project **if** you have not done so. Said differently, you only need to run the following command once.

   ```
   mkdir connect4
   ```

2. Move to the above directory.

   ```
   cd connect4
   ```

3. Create `Board.hpp` with the following contents. **Warning:** do not write `Board.hpp` as `board.hpp`. C++ is a case-sensitive language.

   `Board.hpp` is the header file of Board class that **declares** data members and operations (aka methods) on those data members.

```
#ifndef BOARD_H
#define BOARD_H
#include <vector>
class Board {
public:
    Board(); //6 bins, each bin holds at most 4 balls
    Board(int numBins, int capacity); //numBins, each bin holds at most capacity
   many shapes
    void display() const;
    int add(int player);
        //Given a player,
        //return which bin the player is added to.

    int winInHorizontal(int bin);
    int winInVertical(int bin);
    int winInDiagonal(int bin);

    int win(int bin); //column must be the most recent ball in that bin

    void play();

//private: //TODO: comment private: for gradescope test purpose only
    int numBins; //number of bins
    int capacity; //maximum number of shapes held in each bin
    //need to compile using -std=c++11
    //if using std::vector<std::vector<int>>, otherwise
    //need to use std::vector<std::vector<int> >
    //with a space after the last > >.

    std::vector<std::vector<int> > grid;
    //If not using c++11, need to have space between the last two > >
    //std::vector<std::vector<int> > grid;
    //The above statement cannot write as
    //std::vector<int> grid(numBins, capacity);
    //which results in a one-dimensional array
    //of numBins elements, each element equals capacity.
};
#endif
```

4. Your task is to implement `Board.cpp`, which **defines** constructors and methods declared in Board.hpp.

   (a) Note that, in `Board.hpp`, data members are declared but not yet initialized. The data members are initialized in constructors.

   (b) Similarly, constructors and methods are declared (have function header) in `Board.hpp` but not defined (no function body).

   (c) **Warning:** do NOT put main function in `Board.cpp`.

3 Data Members in Board.hpp

The details of data members, constructors and methods in Board class of the game are discussed as follows.

```
+--+--+--+--+--+--+
|  |  |  |  |  |  |
+--+--+--+--+--+--+
|  |  |  |  |  |  |
+--+--+--+--+--+--+
|  |  |  |  |  |  |
+--+--+--+--+--+--+
|  |  |  |  |  |  |
+--+--+--+--+--+--+
  0  1  2  3  4  5
```

1. Data member `numBins` is an integer representing the number of bins. In the above example, `numBins` is 6. One column is a bin.

2. Data member `capacity` is an integer representing the maximum number of element each bin can hold. In the previous example, `capacity` is 4.

3. Data member `grid` of type `std::vector<std::vector<int>>` is a two dimensional array of integers.

   (a) A vector is a one-dimensional array that can grow or shrink. It is a template class, documentation can be found at `https://cplusplus.com/reference/vector/vector/`.

   (b) To use vector, need to include the library.

   `include <vector>`

      i. If you do not use standard namespace std, then need to add `std::` before vector.

      ii. Example: declare a vector as an array of integers with 4 elements. Each element is initialized to be 1.

```cpp
#include <iostream>
#include <vector>
#include <string>
//using namespace std;

int main() {
    std::vector<int> oneBin = {1, 1, 1, 1};
```

```
        //oneBin is a vector of integers with elements 1, 1, 1, 1.

    for (int i = 0; i < oneBin.size(); i++)
        std::cout << oneBin[i] << std::endl;
    return 0;
}
```

(c) Each bin is represented by a vector of integers, similar to a one-dimensional array of integers. A bin may be empty.

(d) In the beginning, data member `grid` has six bins, each bin is empty.

(e) When displaying, map integer 0 to red circle and integer 1 to blue pentagon. More mapping details are shown in `display` method.

You may think `grid` in the previous example has six bins, each bin can hold at most four (same value as capacity) elements.

Note that data member `capacity` does not suppose a limit on the size of the vector. When this capacity is exhausted and more is needed, it is automatically expanded by the container (reallocating it storage space).

However, for this game, we need to make sure that no bin can have more `capacity` elements at any time. When there is `capacity` elments in a bin, we stop adding elements to that bin.

4 Task A: Define constructors in Board.cpp

The purpose of constructor is to initialize data members. A class may have multiple constructors. Different constructors have different parameter lists. Each constructor has exactly the same name as class, no return type, not even void.

4.1 The default constructor `Board()`

The default constructor does not take any parameter. It does the following:

1. Set data members `numBins` to be 6.
2. Set data member `capacity` to be 4.

   Warning: the following code is wrong. `int` before `numBins` means to the varialbe is a local variable for constructor `Board`, but not data member `numBins`.

```
Board::Board() {
    int numBins = 6;
    ... //omit other code
}
```

Correct way:

```
Board::Board() {
    numBins = 6;
    ... //omit other code
}
```

3. You may use the hints from the following code to initialize data member `grid`.

```
//for each shape, do the following:
for (int i = 0; i < ?; i++) { //TODO: fill in ?
    std::vector<int> oneBin;
       //that is, oneBin is an empty vector
       //You may think oneBin as a bin in our application.


    //add the one-dimensional array oneBin to grid
    grid.push_back(??); //TODO: fill in ??
}
```

4.2 A nondefault constructor `Board(int numBins, int capacity)`

1. If given parameter `numBins` is smaller than 5, reset it to be 5.
2. If given parameter `capacity` is smaller than 4, reset it to be 4.
3. Now given parameters are correct, use them to set the corresponding data members. Note that if a formal parameter has exactly the same name as a data member, we need to put `this->` before the data member, where `this` is a pointer to the current object.

You may notice that there are a lot of common codes among those constructors. A better way is to define `Board(int numBins, int capacity)`. Then use constructor delegate to define `Board()`.

No need to define destructor in this project since we did not dynamically allocate memories for data members.

4.3 Finish Task A

1. Define constructors in `Board.cpp`.

```
#include "Board.hpp"
#include <iostream> //cout
#include <iomanip> //setw
#include <algorithm> //swap

//TODO: fill in ? and ?? in the parentheses.
//Hint: what are the values of numBins and capacity for a default Board object?
//Question: after calling Board(?, ??) to create a Board object with
//? means number of bins,
//each bin holds at most ?? elements,
Board::Board() : Board(?, ??) {
    //No more code is needed
}

Board::Board(int numBins, int capacity) {
    //TODO: If given parameter numBins is smaller than 5,
```

```
    //reset it to be 5.


    //TODO: If given parameter capacity is smaller than 4,
    //reset it to be 4.


    //Now given parameters are correct,
    //use them to set the corresponding data members.
    //Note that if a formal parameter has exactly
    //the same name as a data member,
    //we need to put this-> before the data member,
    //where this is a pointer to the current object.

    //TODO: use formal parameter numBins to set data member numBins


    //TODO: use formal parameter capacity to set data member capacity



    //TODO: initialize data member grid

    //for i in [0, numBins):
    //begin
    //   instantiate an empty bin, call it oneBin
    //   push oneBin back to data members grid
    //end




}
```

2. Implement method `display`.

   See the following hints.

   We provide a non-member function `print`.

```
//not a method from Board class,
//hence cannot access data member capacity directly,
//need to pass capacity as a parameter
void print(int numBins) {
    //No need to print spaces before the first +
    //std::cout << "   ";
    std::cout << "+";
```

```
    for (int i = 0; i < numBins; i++)
        std::cout << "--+";

    std::cout << std::endl;
}
```

Here is a skeleton of method `display`.

```
    //map 0 to a red ball \033[31m\u2b24,
    //where \033[31m is red and \u2b24 is a ball
    //map 1 to a blue pentagon \033[34m\u2b1f
    //where \033[34m is blue and \u2b1f is a pentagon
    //map 2 to a red double circle \033[31m\u25c9
    //where \u25c9 is a double circle
    //map 3 to a blue empty pentagon \033[31m\u2b54
    //where \u2b54 is a pentagon with edges only
    //\033[0m is black color, the default color
    //For more shapes, see https://jrgraphix.net/r/Unicode/25A0-25FF
    std::string mapping[] = {"\033[31m\u2b24\033[0m", "\033[34m\u2b1f\033[0m", "
   \033[31m\u25c9\033[0m", "\033[34m\u2b54\033[0m"}; //\033[32m is green color

    print(numBins);
    for (int j = capacity-1; j >= 0; j--) {
        //Your codes goes here.
        //Instead of printing grid[i][j],
        //where i is bin index,
        //you may consider using mapping[grid[i][j]].




    }

    //TODO: print labels

}
```

3. Implement method `add`.

```
int Board::add(int player) {
    //TODO:
    //(1) Given player,
    //    choose a bin index that is valid,
    //    ie, in [0, numBins),
    //    and is not full.
    //(2) push back this player id to that bin.
    //(3) return the bin index chosen.

```

```
10
11
12
13 }
```

4. Test codes locally.

   (a) Comment private: line in `Board.hpp` as `//private:`. This is for debug purpose.

   (b) Edit main.cpp as follows. This file can be downloaded from `https://onlinegdb.com/aedvljUjk`.

```cpp
#include <iostream>
#include <vector>
#include "Board.hpp"
//g++ -std=c++11 Board.cpp main.cpp -o test
//test default constructor using
//./test A or ./test 'A'
//./test B or ./test 'B'
//...
//./test H or ./test 'H'


int main(int argc, const char *argv[]) {
    if (argc != 2) {
       std::cout << "Need 'A'-'C' in parameters" << std::endl;
       return -1;
    }

    //unit-testing for constructors and the destructor
    char type = *argv[1];
    std::string prompt;
    Board *game;
    int** arr;

    if (type == 'A') {
       prompt = "default constructor,";
       game = new Board;

//Sample output:
//After default constructor, data member numBins is 6
//After default constructor, data member capacity is 4
//number of elements of bin 0 is: 0
//number of elements of bin 1 is: 0
//number of elements of bin 2 is: 0
//number of elements of bin 3 is: 0
//number of elements of bin 4 is: 0
//number of elements of bin 5 is: 0
    }
```

```
38      else if (type == 'B') {
39              prompt = "Board game(7, 5);";
40              game = new Board(7, 5);
41
42  //Sample output:
43  //After Board game(7, 5); data member numBins is 7
44  //After Board game(7, 5); data member capacity is 5
45  //number of elements of bin 0 is: 0
46  //number of elements of bin 1 is: 0
47  //number of elements of bin 2 is: 0
48  //number of elements of bin 3 is: 0
49  //number of elements of bin 4 is: 0
50  //number of elements of bin 5 is: 0
51  //number of elements of bin 6 is: 0
52      }
53      else if (type == 'C') {
54              prompt = "Board game(5, 1);";
55              game = new Board(5, 1);
56
57  //sample output:
58  //After Board game(5, 1); data member numBins is 5
59  //After Board game(5, 1); data member capacity is 4
60  //number of elements of bin 0 is: 0
61  //number of elements of bin 1 is: 0
62  //number of elements of bin 2 is: 0
63  //number of elements of bin 3 is: 0
64  //number of elements of bin 4 is: 0
65      }
66      else if (type == 'D') {
67              game = new Board;
68
69              game->grid[0].push_back(0);
70              game->grid[0].push_back(1);
71              game->grid[1].push_back(0);
72              game->grid[1].push_back(1);
73              game->grid[2].push_back(0);
74              game->grid[3].push_back(1);
75              game->display();
76
77  //sample output:
78  //+--+--+--+--+--+--+
79  //|  |  |  |  |  |  |
80  //+--+--+--+--+--+--+
81  //|  |  |  |  |  |  |
82  //+--+--+--+--+--+--+
83  //|    |    |  |  |  |  |
```

```
//+--+--+--+--+--+--+
//|  |  |  |  |  |  |
//+--+--+--+--+--+--+
//  0  1  2  3  4  5
    }
    else if (type == 'E') {
            game = new Board;

            game->grid[0].push_back(2);
            game->grid[0].push_back(1);
            game->grid[1].push_back(2);
            game->grid[1].push_back(1);
            game->grid[2].push_back(2);
            game->grid[2].push_back(1);
            game->grid[3].push_back(2);
            game->display();
//sample output:
//+--+--+--+--+--+--+
//|  |  |  |  |  |  |
//+--+--+--+--+--+--+
//|  |  |  |  |  |  |
//+--+--+--+--+--+--+
//|  |  |  |  |  |  |
//+--+--+--+--+--+--+
//|  |  |  |  |  |  |
//+--+--+--+--+--+--+
//  0  1  2  3  4  5
    }
    else if (type == 'F') {
            game = new Board;

            game->grid[0].push_back(0);
            game->grid[1].push_back(3);
            game->grid[0].push_back(0);
            game->grid[1].push_back(3);
            game->grid[0].push_back(0);
            game->grid[1].push_back(3);
            game->grid[3].push_back(0);
            game->grid[1].push_back(3);
            game->display();

//sample output:
//+--+--+--+--+--+--+
//|  |  |  |  |  |  |
//+--+--+--+--+--+--+
//|  |  |  |  |  |  |
```

```
//+--+--+--+--+--+--+
//|  |  |  |  |  |  |
//+--+--+--+--+--+--+
//|  |  |  |  |  |  |
//+--+--+--+--+--+--+
//  0  1  2  3  4  5
    }
    else if (type == 'G') {
            game = new Board;
            int bin = game->add(0); //choose a bin for player with id 0
            int bin2 = game->add(1); //choose a bin for player with id 1

            std::cout << "The layout of the bins are as follows." << std::endl
   ;
            for (int i = 0; i < game->numBins; i++) {
                if (game->grid[i].size() == 0)
                   std::cout << "empty" << std::endl;
                else {
                      for (int j = 0; j < game->grid[i].size(); j++)
                          std::cout << game->grid[i][j] << " ";
                      std::cout << std::endl;
                }
            }

//sample output:
//Enter a bin index in [0, 6) that is not full: -1
//invalid bin index, needs to be in [0, 6)
//Re-enter a bin index in [0, 6) that is not full: 7
//invalid bin index, needs to be in [0, 6)
//Re-enter a bin index in [0, 6) that is not full: 0
//Enter a bin index in [0, 6) that is not full: -2
//invalid bin index, needs to be in [0, 6)
//Re-enter a bin index in [0, 6) that is not full: 10
//invalid bin index, needs to be in [0, 6)
//Re-enter a bin index in [0, 6) that is not full: 1
//The layout of the bins are as follows.
//0
//1
//empty
//empty
//empty
//empty
    }
    else if (type == 'H') {
            //When a bin is full, cannot add more element to it.
            game = new Board;
```

```
175             game->grid[0].push_back(0);
176             game->grid[0].push_back(1);
177             game->grid[0].push_back(0);
178             game->grid[0].push_back(1);
179             int bin = game->add(0); //choose a bin for player with id 0
180
181             std::cout << "The layout of the bins are as follows." << std::endl
    ;
182             for (int i = 0; i < game->numBins; i++) {
183                 if (game->grid[i].size() == 0)
184                    std::cout << "empty" << std::endl;
185                 else {
186                       for (int j = 0; j < game->grid[i].size(); j++)
187                           std::cout << game->grid[i][j] << " ";
188                       std::cout << std::endl;
189                 }
190             }
191 //sample output:
192 //Enter a bin index in [0, 6) that is not full: 0
193 //the bin is full
194 //Re-enter a bin index in [0, 6) that is not full: 1
195 //The layout of the bins are as follows.
196 //0 1 0 1
197 //0
198 //empty
199 //empty
200 //empty
201 //empty
202     }
203
204     //When type is 'A' - 'C', work on constructors
205     if (type == 'A' || type == 'B' || type == 'C') {
206        std::cout << "After " << prompt
207             << " data member numBins is " << game->numBins << std::endl;
208        std::cout << "After " << prompt
209             << " data member capacity is " << game->capacity << std::endl;
210
211        for (int i = 0; i < game->numBins; i++) {
212            std::cout << "number of elements of bin "
213                << i << " is: "
214                << game->grid[i].size() << std::endl;
215
216         }
217     }
218
219     delete game;
```

```
    game = nullptr;

    return 0;
}
```

(c) Run the following command to compile main.cpp and Board.cpp.

`g++ -std=c++11 main.cpp Board.cpp -o test`

(d) If there is no compilation errors, run the following command.

`./test A`

(e) You should be able see something like the following.

```
After default constructor, data member numBins is 6
After default constructor, data member capacity is 4
number of elements of bin 0 is: 0
number of elements of bin 1 is: 0
number of elements of bin 2 is: 0
number of elements of bin 3 is: 0
number of elements of bin 4 is: 0
number of elements of bin 5 is: 0
```

(f) Test non-default construtor `Board(int numBins, int capacity)` by using

`./test B`

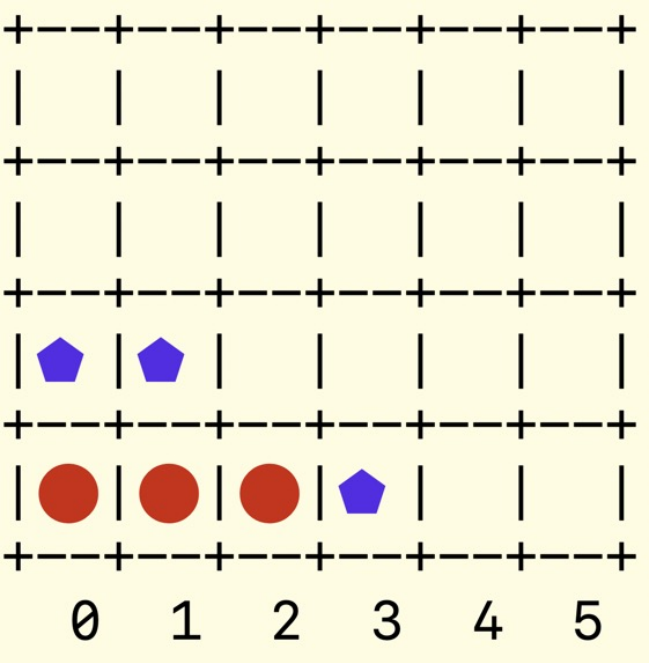
You should see the following output.

```
After Board game(7, 5); data member numBins is 7
After Board game(7, 5); data member capacity is 5
number of elements of bin 0 is: 0
number of elements of bin 1 is: 0
number of elements of bin 2 is: 0
number of elements of bin 3 is: 0
number of elements of bin 4 is: 0
number of elements of bin 5 is: 0
number of elements of bin 6 is: 0
```

5. Run `./test C`, we get the following output.

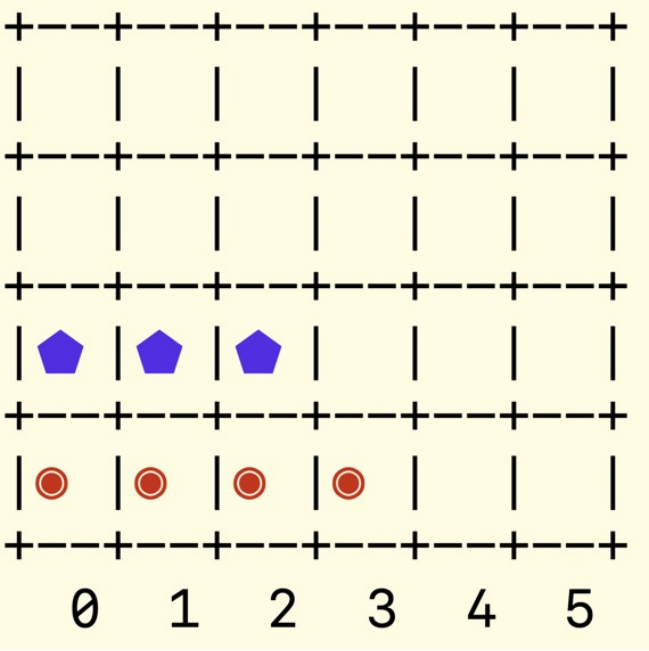
```
After Board game(5, 1); data member numBins is 5
After Board game(5, 1); data member capacity is 4
number of elements of bin 0 is: 0
number of elements of bin 1 is: 0
number of elements of bin 2 is: 0
number of elements of bin 3 is: 0
number of elements of bin 4 is: 0
```

6. Run `./test D`. Get the following output.



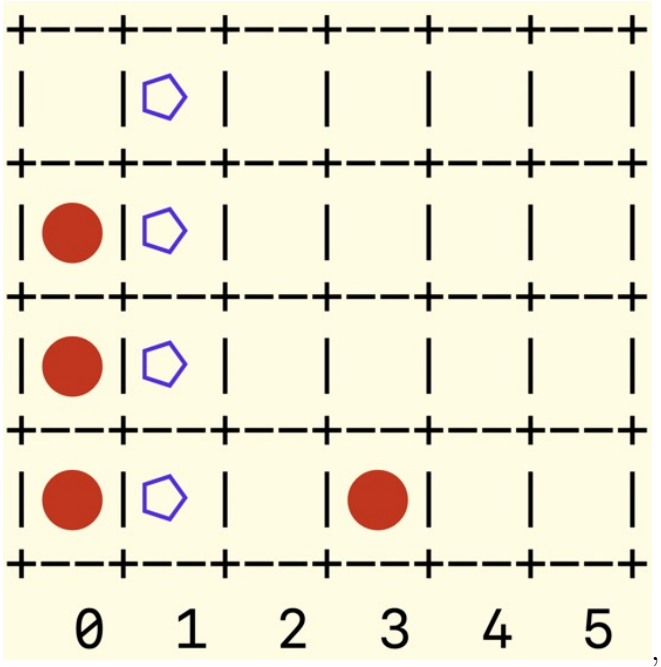
,

7. Run `./test E`. Get the following output.



,

8. Run `./test F`. Get the following output.



,

9. Or you can test the code in `https://www.onlinegdb.com/online_c++_compiler`.

   Upload main.cpp, Board.hpp (comment private: line) and Board.cpp to onlinegdb. In the textbox right to **Command line arguments:**, enter A to H.

10. If the code runs correctly in a local computer, upload `Board.cpp` to gradescope.

11. Again, do not add `main` function in `Board.cpp`.

5 Task B: define winHorizontal, winVertical, winDiagonal, and win methods

After a player puts a shape to a bin using `add` method in Task A, an id (either 0 or 1) representing that player is pushed back to the bin. There is a chance the player could win.

5.1 A win or not

To find out whether there is an actual win or not, define method `winInHorizontal`, given a bin, check whether its top element (including itself) has 4 or more same-value neighbors in horizontal direction. Simiarly, methods `winInVertical` and `winInDiagonal` (including diagonal and anti-diagonal) are defined.

5.2 With a win, save the locations of four or more consecutive same-value elements in the corresponding direction

Furthermore, once a win occurs, we would like to mark out those 4 or more consecutive elements in the correspondin direction. To do so, we need to record the location of an element.

Use type `Coord` to save the location of an element, where `bin` is the bin index and `idx` is the index of the element in `bin`.

```
struct Coord {
    int bin; //bin index of data member grid
    int idx; //index inside the bin
};
```

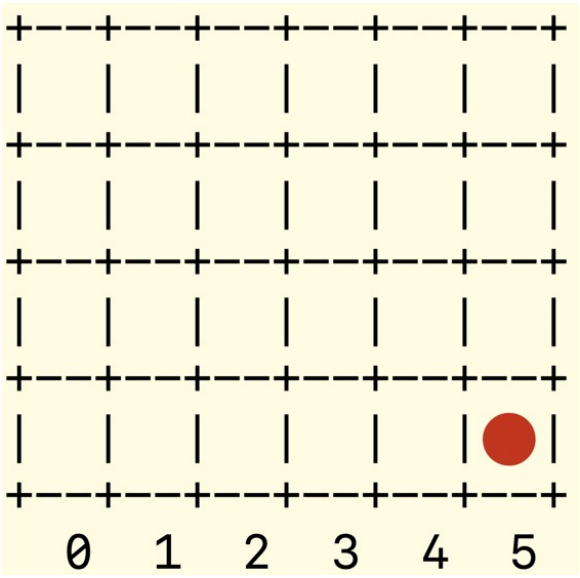
Some students ask the differences between `struct` and `class` in C++.

1. Both `struct` and `class` define a type.
2. `struct` also works in C. Unlike an array, which is a collection of same-type data residing in consecutive memory, a `struct` consists of members of different types, but without methods or constructor (this part changes in C++), while `class` is defined in C++.
3. By default, members in `struct` are public.
4. By default, members in `class` are private.
5. According to `https://stackoverflow.com/questions/54585/when-should-you-use-a-class-vs-a-str` we can do the following.
   (a) Use struct for plain-old-data structures without any class-like features.
   (b) Use class when you make use of features such as private or protected members, non-default constructors and operators.

Put the locations of those elements in a vector. If the size of that vector is larger than or equal to 4, increase the value of those elements by 2. In this way, those four or more consecutive elements in the path can be marked out, so we can see clearly why a player wins.

We illustrate a run of method `winInHorizontal`.

1. In the beginning, player red (with id 0) puts 0, which maps to a red circle, into bin 5.

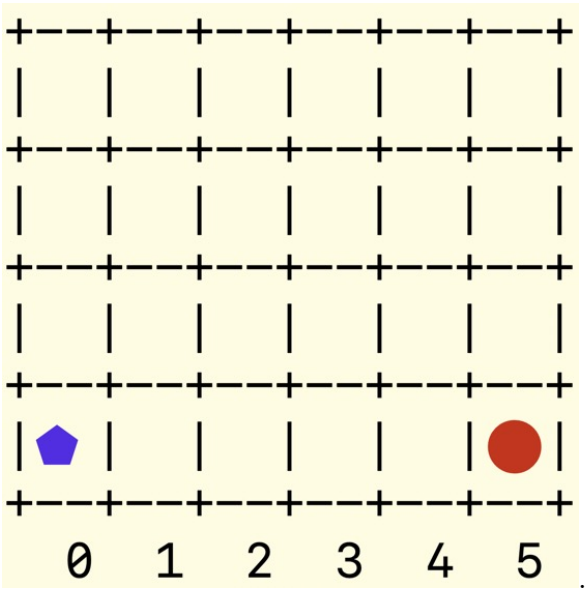


The above process is achieved by the following statements, taken from `main.cpp` to test methods in Task B.

Note that we do not call methods to put elements to bins in case other methods are not properly defined. We just concentrate on testing on `winInHorizontal` method.

```
game = new Board; //default constructor
game->grid[5].push_back(0);
//game->display(); //optional,
```

2. Next, player blue (with id 1) puts a 1, which maps to a blue pentagon, into bin 0.

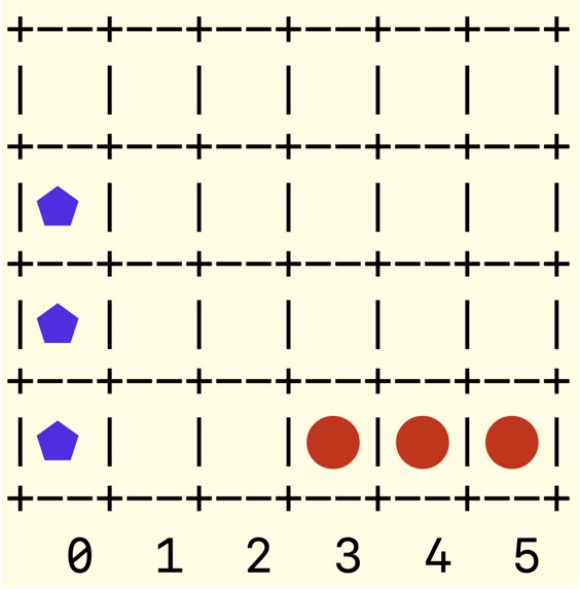


This is achieved by adding the following statements to the above codes.

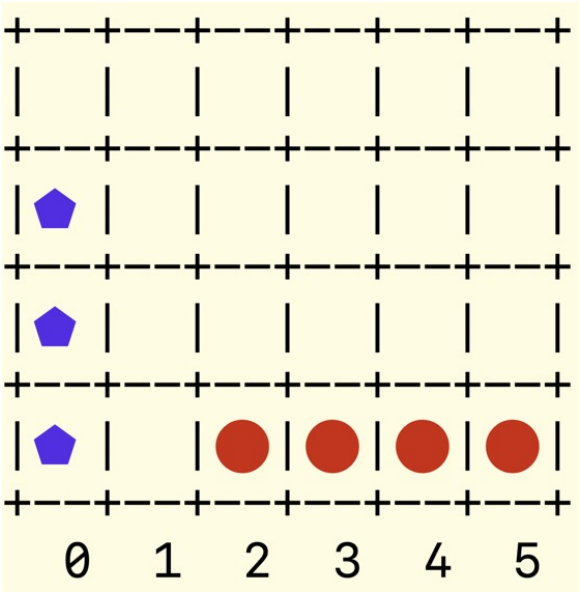
```
game->grid[0].push_back(1);
```

3. Fastforward, the layout of bins are as follows after player 0 chooses bin 4, player 1 choose bin 0, then player 0 chooses bin 3, player 1 chooses bin 0.

```
game->grid[4].push_back(0); //player 0 chooses bin 4
game->grid[0].push_back(1); //player 1 chooses bin 0
game->grid[3].push_back(0); //player 0 chooses bin 3
game->grid[0].push_back(1); //player 1 chooses bin 0
```



4. Now is the turn of player 0. If bin 2 is chosen, then four 0s (each 0 is mapped to a red circle) are aligned consecutively in horizontal direction.



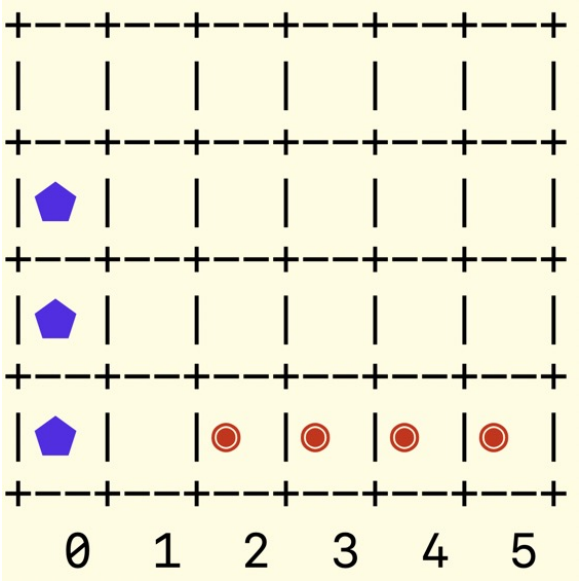

```
game->grid[2].push_back(0);
```

5. Test `winInHorizontal` method on bin 2, the most recent bin with a new element added. In this example, the return should be 0, the id of the player who wins the game. That is, player 0 wins in horizontal direction.

   If there is no winner, return -1.

```
player = game->winInHorizontal(2);
```

6. To show users why player 0 wins, we display the corresponding elements in slightly different shapes, from the original red circles to double red circles. To do so, we add 2 to the original value 0. By the mapping in display method, label 2 is mapped to a double red circle.



Here is expected result after test option 1 in the above main function, where each column represents a bin. Display the elements for each bin from top to bottom, if there is no element, use a space.

The first bin has three blue pentagons, represented by id 1. In bins indexed at 2, 3, 4, 5, each has one element 2, which implies that player 0 wins.

```
player 0 wins in horizontal
 , , , , , ,
1, , , , , ,
1, , , , , ,
1, ,2,2,2,2,
```

5.3 Method `winInHorizontal`

In short, method `int winInHorizontal(int bin)` does the following.

1. Find out the player id in the top of `bin`. (Hint: what is the last index of `bin`, a vector of integers?
2. Count the number of consecutive same-value as the above player id elements in horizontal direction.
   (a) Record the locations, that is, bin index and the index in the bin, to a vector variable.
3. If the number of consecutive same-value elements in horizontal direction is at least four, set the player id as the winner.
4. Increase the corresponding elements contributed to the win by 2. That is, if the original value is 0, the new value is 2. If the original value is 1, the new value would be 3.

Here is a skeleton of method `winInHorizontal`.

```
int Board::winInHorizontal(int bin) {
    //Find out the last index of bin.

```

```
    //Find out the player residing at that last index of bin.
    //Save in an int variable called player.

    //Declare candidates as a vector of Coord.

    //candidates saves the locations of
    //all horizontal neighbors of the top elements of the given parameter bin
    //that share the same value of that top element,
    //which is saved in player.


    //Who can be the first element of candidates?


    //count consecutive elements equaling player to the left of grid[bin][idx]. Save
  their locations to candidates.

    //count consecutive elements equaling player to the right of grid[bin][idx]. Save
  their locations to candidates.

    if (count >= 4) {
       //change all elements in candidates to e player +2

       return player;
    }

    //Return -1 when no winner in horizontal direction
}
```

Define `winInVertical` method.

Define `winInDiagonal` method, need to consider both diagonal and anti-diagonal directions.

Define `win` method, which calls `winInHorizontal`, `winInVertical`, and `winInDiagonal` methods, if one of them return a value other than -1, then a winner is found, return the corresponding player id, otherwise, return -1.

5.4 Test code locally

1. Create a subdirectory called `taskB` under `connect4`.
2. In `taskB`, copy `Board.cpp` from Task A.
   (a) Define `winInHorizontal`, `winInVertical`, `winInDiagonal`, and `win` methods in `Board.cpp`.
3. Download the following `main.cpp` and `Board.hpp` from `https://onlinegdb.com/7buWVilKs` to subdirectory `taskB`.
   (a) Run command

```
g++ -std=c++11 Board.cpp main.cpp -o test
```

Test methods in Task B using the following commands. Compare the output with sample output in each test case of `main.cpp`.

```
./test 1
```

There are 9 cases to test. Change 1 to 2, 3, ..., 9 if necessary.

If codes run fine, upload `Board.cpp` to gradescope.

Warning: some unicode symbols are not shown in the following codes, download from the previous onlinegdb link or brightspace.

```cpp
#include <iostream>
#include <vector>
#include "Board.hpp"
//g++ -std=c++11 Board.cpp main.cpp -o test
//test different methods using
//./test 1 or ./test '1'
//./test 2 or ./test '2'
//...
//./test 9 or ./test '9'


int main(int argc, const char *argv[]) {
    if (argc != 2) {
        std::cout << "Need 'A'-'C' in parameters" << std::endl;
        return -1;
    }

    //unit-testing for constructors and the destructor
    char type = *argv[1];
    std::string prompt;
    Board *game;
    int player = -2; //a not-exist value

    if (type == '1') {
        //test player 0 wins in winInHorizontal
        game = new Board; //default constructor
        game->grid[5].push_back(0);
        //game->display();
        game->grid[0].push_back(1);
        //game->display();
        game->grid[4].push_back(0);
        //game->display();
        game->grid[0].push_back(1);
        //game->display();
        game->grid[3].push_back(0);
```

```
36          //game->display();
37          game->grid[0].push_back(1);
38          //game->display();
39          game->grid[2].push_back(0);
40          //game->display();
41
42          player = game->winInHorizontal(2);
43          prompt = " in horizontal";
44
45          //game->display();
46  //Sample output:
47  //player 0 wins in horizontal
48  // , , , , , ,
49  //1, , , , , ,
50  //1, , , , , ,
51  //1, ,2,2,2,
52  //+--+--+--+--+--+--+
53  //|  |  |  |  |  |  |
54  //+--+--+--+--+--+--+
55  //|    |  |  |  |  |  |
56  //+--+--+--+--+--+--+
57  //|    |  |  |  |  |  |
58  //+--+--+--+--+--+--+
59  //|    |  |    |    |    |    |
60  //+--+--+--+--+--+--+
61  //  0  1  2  3  4  5
62      }
63      else if (type == '2') {
64          //test no one wins in winInHorizontal
65          game = new Board; //default constructor
66          game->grid[5].push_back(0);
67          game->grid[0].push_back(1);
68          game->grid[4].push_back(0);
69          game->grid[0].push_back(1);
70          game->grid[3].push_back(0);
71          game->grid[0].push_back(1);
72
73          player = game->winInHorizontal(0);
74          prompt = " in horizontal";
75          //game->display();
76  //Sample output:
77  //no player wins in horizontal
78  // , , , , , ,
79  //1, , , , , ,
80  //1, , , , , ,
81  //1, , ,0,0,0,
```

```
82  //Visual result
83  //+--+--+--+--+--+--+
84  //|  |  |  |  |  |  |
85  //+--+--+--+--+--+--+
86  //|    |  |  |  |  |  |
87  //+--+--+--+--+--+--+
88  //|    |  |  |  |  |  |
89  //+--+--+--+--+--+--+
90  //|    |  |  |    |    |    |
91  //+--+--+--+--+--+--+
92  //  0  1  2  3  4  5
93      }
94      else if (type == '3') {
95          //win in vertical
96          game = new Board;
97
98          game->grid[0].push_back(0);
99          game->grid[1].push_back(1);
100         game->grid[0].push_back(0);
101         game->grid[1].push_back(1);
102         game->grid[0].push_back(0);
103         game->grid[1].push_back(1);
104         game->grid[3].push_back(0);
105         game->grid[1].push_back(1);
106         //game->display();
107
108         player = game->winInVertical(1);
109         prompt = " in vertical";
110
111 //sample output:
112 //player 1 wins in vertical
113 // ,3, , , , ,
114 //0,3, , , , ,
115 //0,3, , , , ,
116 //0,3, ,0, , ,
117 //+--+--+--+--+--+--+
118 //|  |    |  |  |  |  |
119 //+--+--+--+--+--+--+
120 //|    |    |  |  |  |  |
121 //+--+--+--+--+--+--+
122 //|    |    |  |  |  |  |
123 //+--+--+--+--+--+--+
124 //|    |    |  |    |  |  |
125 //+--+--+--+--+--+--+
126 //  0  1  2  3  4  5
127     }
```

```
128     else if (type == '4') {
129         //no win in vertical
130         game = new Board;
131 
132         game->grid[0].push_back(0);
133         game->grid[1].push_back(1);
134         game->grid[0].push_back(0);
135         game->grid[1].push_back(1);
136         game->grid[0].push_back(0);
137         game->grid[1].push_back(1);
138         //game->display();
139 
140         player = game->winInVertical(1);
141         prompt = " in vertical";
142 //Sample output:
143 //+--+--+--+--+--+--+
144 //|  |  |  |  |  |  |
145 //+--+--+--+--+--+--+
146 //|   |   |  |  |  |  |
147 //+--+--+--+--+--+--+
148 //|   |   |  |  |  |  |
149 //+--+--+--+--+--+--+
150 //|   |   |  |  |  |  |
151 //+--+--+--+--+--+--+
152 //  0  1  2  3  4  5
153 //no player wins in vertical
154 // , , , , , ,
155 //0,1, , , , ,
156 //0,1, , , , ,
157 //0,1, , , , ,
158     }
159     else if (type == '5') {
160         //win in diagonal
161         game = new Board;
162         game->grid[0].push_back(0);
163         game->grid[1].push_back(1);
164         game->grid[1].push_back(0);
165         game->grid[2].push_back(1);
166         game->grid[3].push_back(0);
167         game->grid[2].push_back(1);
168         game->grid[2].push_back(0);
169         game->grid[3].push_back(1);
170         game->grid[3].push_back(0);
171         game->grid[4].push_back(1);
172         game->grid[3].push_back(0);
173 
```

```
174         player = game->winInDiagonal(0);
175         prompt = " in diagonal";
176 
177         //game->display();
178 
179 //Sample output:
180 //player 0 wins in diagonal
181 // , , ,2, , ,
182 // , ,2,0, , ,
183 // ,2,1,1, , ,
184 //2,1,1,0,1, ,
185 //+--+--+--+--+--+--+
186 //|  |  |  |  |  |  |
187 //+--+--+--+--+--+--+
188 //|  |  |  |  |  |  |
189 //+--+--+--+--+--+--+
190 //|  |  |  |  |  |  |
191 //+--+--+--+--+--+--+
192 //|  |  |  |  |  |  |
193 //+--+--+--+--+--+--+
194 //  0  1  2  3  4  5
195     }
196     else if (type == '6') {
197             //win in anti-diagonal
198         game = new Board;
199         game->grid[0].push_back(0);
200         game->grid[1].push_back(1);
201         game->grid[2].push_back(0);
202         game->grid[3].push_back(1);
203         game->grid[0].push_back(0);
204         game->grid[2].push_back(1);
205         game->grid[0].push_back(0);
206         game->grid[0].push_back(1);
207         game->grid[1].push_back(0);
208         game->grid[1].push_back(1);
209 
210         player = game->winInDiagonal(1);
211         prompt = " in anti-diagonal";
212 
213         //game->display();
214 
215 //sample output:
216 //+--+--+--+--+--+--+
217 //|  |  |  |  |  |  |
218 //+--+--+--+--+--+--+
219 //|  |  |  |  |  |  |
```

```
//+--+--+--+--+--+--+
//|  |  |  |  |  |  |
//+--+--+--+--+--+--+
//|  |  |  |  |  |  |
//+--+--+--+--+--+--+
//  0  1  2  3  4  5
//player 1 wins in anti-diagonal
//3, , , , , ,
//0,3, , , , ,
//0,0,3, , , ,
//0,1,0,3, , ,
    }
    else if (type == '7') {
        //no win, a tie
        //msg = '0 1  0 2 0  0 3 1 2 1 1 2 3  3 5  3 5 5 4 4 4 5  4  2\n'
        game = new Board;
        game->grid[0].push_back(0);
        game->grid[1].push_back(1);
        game->grid[0].push_back(0);
        game->grid[2].push_back(1);
        game->grid[0].push_back(0);
        game->grid[0].push_back(1);
        game->grid[3].push_back(0);
        game->grid[1].push_back(1);
        game->grid[2].push_back(0);
        game->grid[1].push_back(1);
        game->grid[1].push_back(0);
        game->grid[2].push_back(1);
        game->grid[3].push_back(0);
        game->grid[3].push_back(1);
        game->grid[5].push_back(0);
        game->grid[3].push_back(1);
        game->grid[5].push_back(0);
        game->grid[5].push_back(1);
        game->grid[4].push_back(0);
        game->grid[4].push_back(1);
        game->grid[4].push_back(0);
        game->grid[5].push_back(1);
        game->grid[4].push_back(0);
        game->grid[2].push_back(1);

        player = game->win(1);

        //game->display();
//sample output:
//+--+--+--+--+--+--+
```

```
266 //|   |   |   |   |   |   |
267 //+--+--+--+--+--+--+--+
268 //|   |   |   |   |   |   |
269 //+--+--+--+--+--+--+--+
270 //|   |   |   |   |   |   |
271 //+--+--+--+--+--+--+--+
272 //|   |   |   |   |   |   |
273 //+--+--+--+--+--+--+--+
274 //  0  1  2  3  4  5
275 //no player wins
276 //1,0,1,1,0,1,
277 //0,1,1,1,0,1,
278 //0,1,0,0,1,0,
279 //0,1,1,0,0,0,
280     }
281     else if (type == '8') {
282         //msg = '0 1 0 2 1 3 0 4\n'
283         game = new Board;
284         game->grid[0].push_back(0);
285         game->grid[1].push_back(1);
286         game->grid[0].push_back(0);
287         game->grid[2].push_back(1);
288         game->grid[1].push_back(0);
289         game->grid[3].push_back(1);
290         game->grid[0].push_back(0);
291         game->grid[4].push_back(1);
292 
293         player = game->win(4); //4 is the most recent bin with balls added
294 
295         //game->display();
296 //sample output:
297 //+--+--+--+--+--+--+--+
298 //|  |  |  |  |  |  |  |
299 //+--+--+--+--+--+--+--+
300 //|   |  |  |  |  |  |  |
301 //+--+--+--+--+--+--+--+
302 //|   |   |  |  |  |  |  |
303 //+--+--+--+--+--+--+--+
304 //|   |   |   |   |   |  |  |
305 //+--+--+--+--+--+--+--+
306 //  0  1  2  3  4  5
307 //player 1 wins
308 // , , , , , , ,
309 //0, , , , , , ,
310 //0,0, , , , , ,
311 //0,3,3,3,3, ,
```

```
312     }
313     else if (type == '9') {
314         //msg = '1 0 1 2 1 3 1\n'
315         game = new Board;
316         game->grid[1].push_back(0);
317         game->grid[0].push_back(1);
318         game->grid[1].push_back(0);
319         game->grid[2].push_back(1);
320         game->grid[1].push_back(0);
321         game->grid[3].push_back(1);
322         game->grid[1].push_back(0);
323 
324         player = game->win(1); //1 is the most recent bin with balls added
325 
326 //        game->display();
327 //sample output:
328 //+--+--+--+--+--+--+
329 //|  |   |  |  |  |  |
330 //+--+--+--+--+--+--+
331 //|  |   |  |  |  |  |
332 //+--+--+--+--+--+--+
333 //|  |   |  |  |  |  |
334 //+--+--+--+--+--+--+
335 //|   |   |   |   |  |  |
336 //+--+--+--+--+--+--+
337 //  0  1  2  3  4  5
338 //player 0 wins
339 // ,2, , , , ,
340 // ,2, , , , ,
341 // ,2, , , , ,
342 //1,2,1,1, , ,
343     }
344 
345     if (player != -1)
346        std::cout << "player " << player << " wins";
347     else std::cout << "no player wins";
348 
349     std::cout << prompt << std::endl;
350 
351     for (int j = game->capacity-1; j>=0; j--) {
352            for (int i = 0; i < game->numBins; i++) {
353                if (j < game->grid[i].size())
354                   std::cout << game->grid[i][j] << ",";
355                else std::cout << " ,";
356            }
357            std::cout << std::endl;
```

```
        }

    delete game;
    game = nullptr;

    return 0;
}
```

6 Task C: define play method

Main steps of `play` method are as follows.

1. Display an empty grid (no element in any cell). Which method should be call?
2. Keep doing the followin until either a winner is found or every cell in the grid is filled.
   (a) In each round, call `add` method on player 0 and 1 alternatively, where player 0 starts first.
   (b) Display the grid after each call of `add`
3. Once we are out of the above loop, either a winner is found or all cells are filled and no one wins, in that situation, print "a tie".
4. To pass gradescope, need to pay attention to the following details.
   (a) In each round, player 0 (mapping to a red circle) plays first, and player 1 (mapping to a blue pentagon in display methoe) plays next.
   (b) The prompt for `add` method must start with "Enter ...". For example, "Enter an index in [0, $numBins$): ", where numBins is the number of bins.
   (c) Once the game is finished, output a line like "winner: red" or "winner: blue" or "a tie".

6.1 Test codes locally

Here is `main.cpp` for Task C.

```
#include "Board.hpp"
#include <iostream>
#include <string>
using namespace std;

//compile and link using command
//g++ -std=c++11 Board.cpp main.cpp -o test
//Then run
//./test A
//or
//./test B

```

```
int main(int argc, const char* argv[]) {
    if (argc != 2) {
       cout << "Need add an integer, like A, after ./a.out" << endl;
       return -1;
    }

    switch (*argv[1]) {
        case 'A':
        {
            Board game;
            game.play();
            break;
        }
        case 'B':
        {
            Board game(7,5);
            game.play();
            break;
        }
    }

    return 0;
}
```

Compile and link the code using command

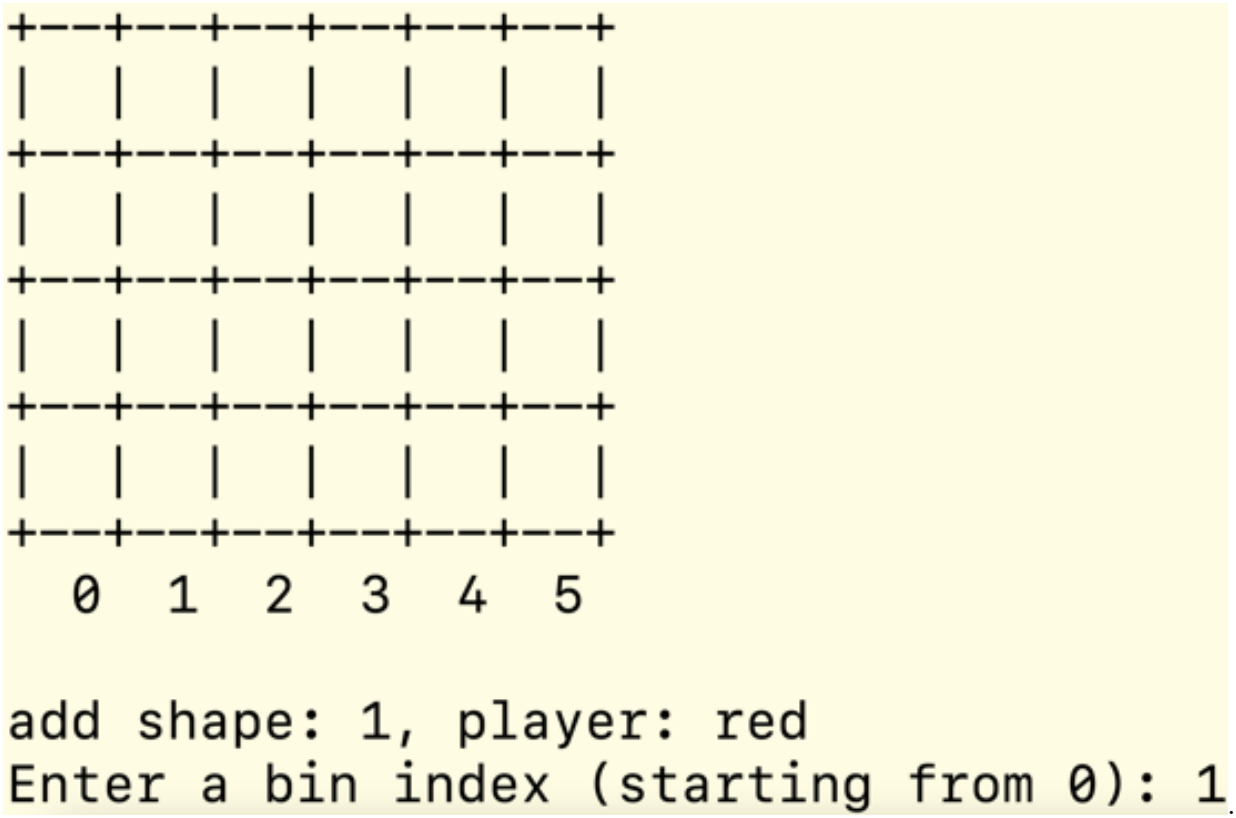
```
g++ -std=c++11 main.cpp Board.cpp -o test
```

Then run the following command to call `play` method of a default Board object.

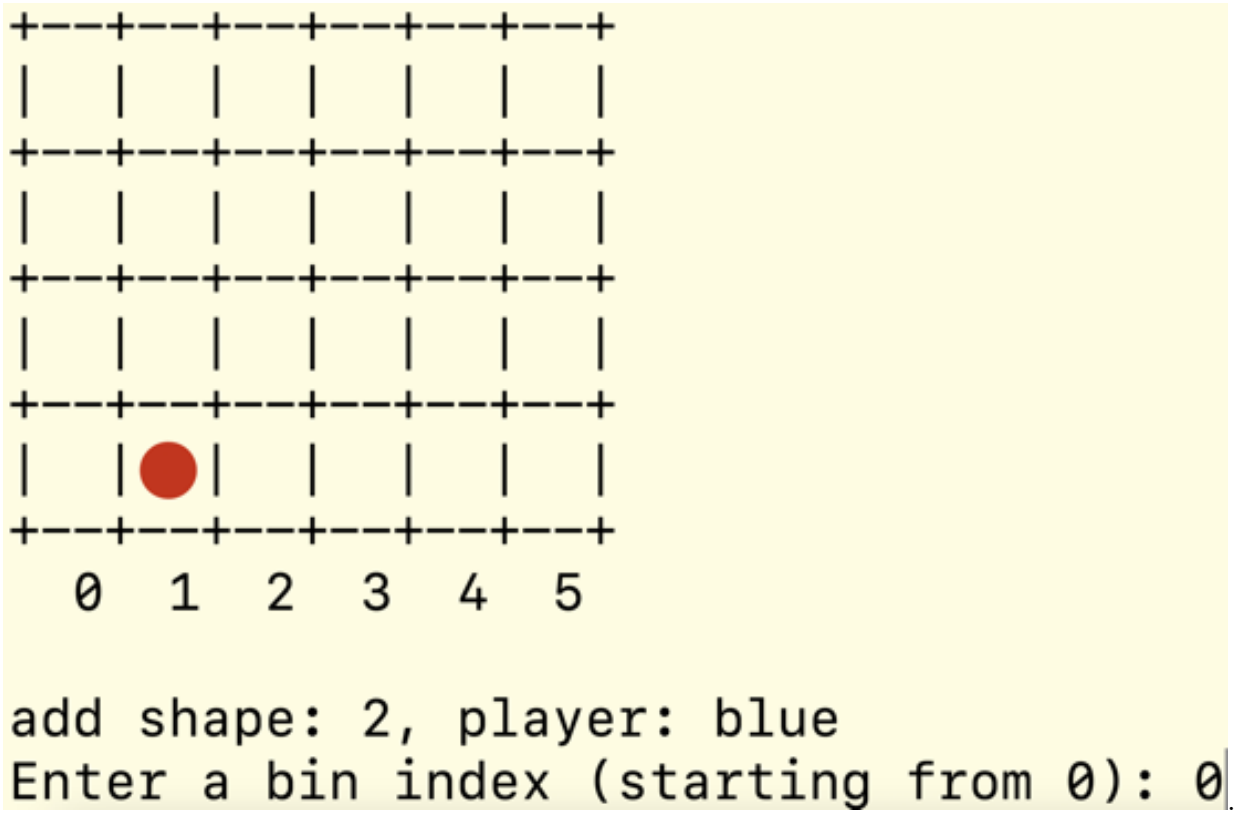
```
./test A
```

6.2 a sample run

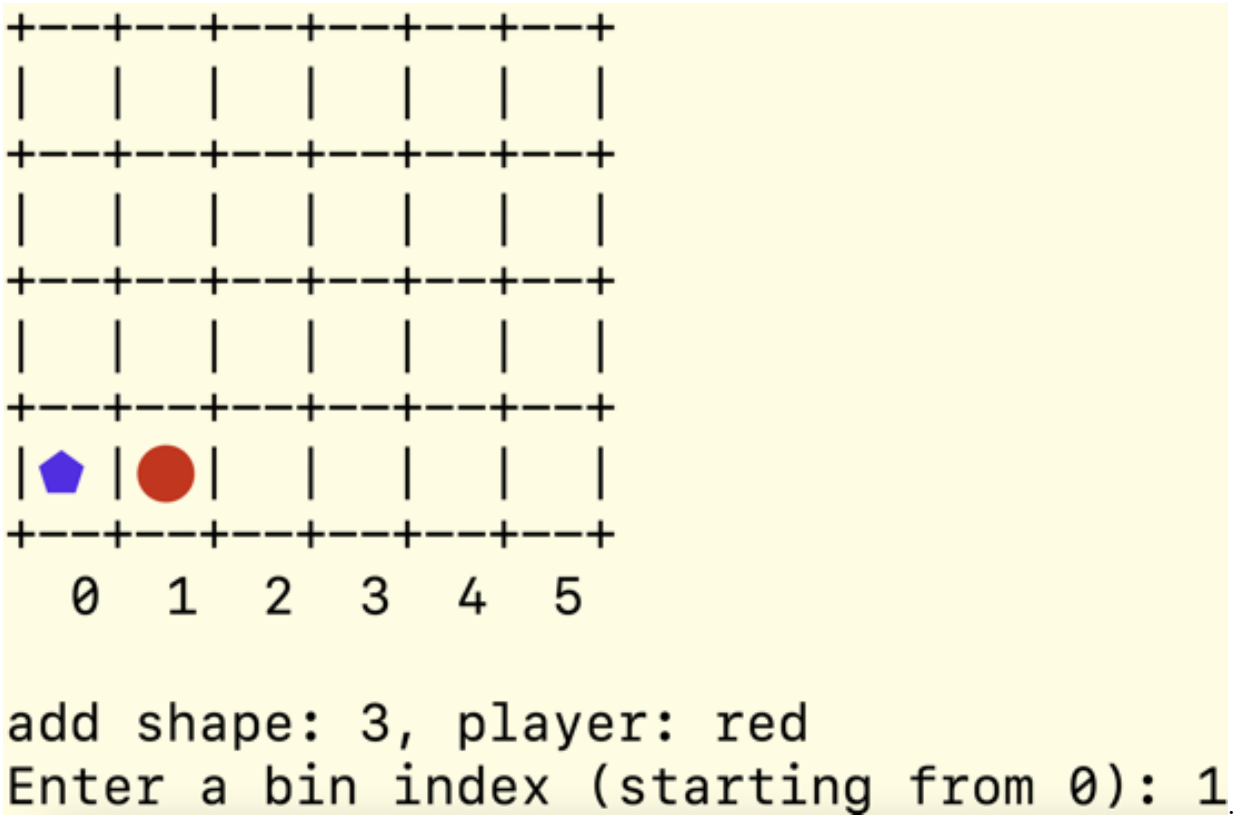
1. Display an empty grid. Enter 1 with return key to put red circle to bin 1.



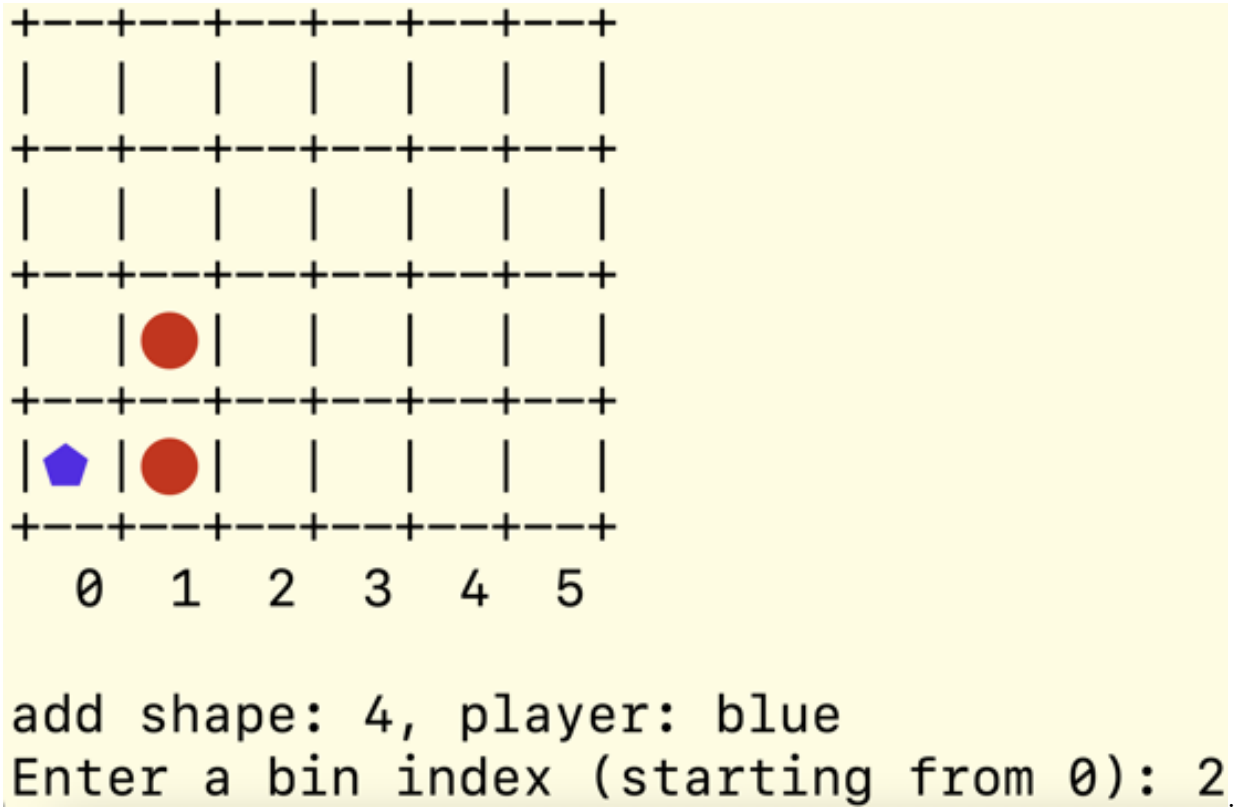
2. Enter 0 with return key to put blue pentagon to bin 0. Note prompt "add shape: " means the number of shapes to be added to the grid.



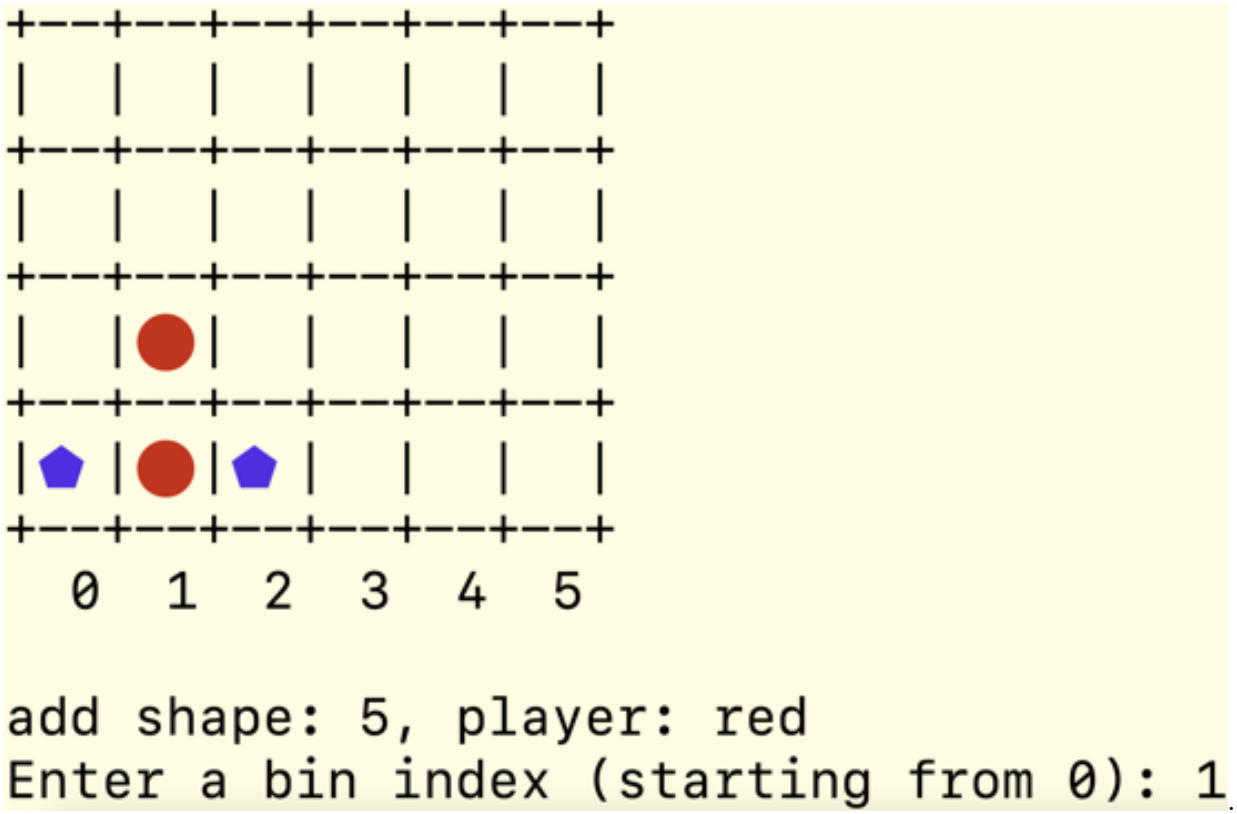
3. Enter 1 to put red circle to bin 1.



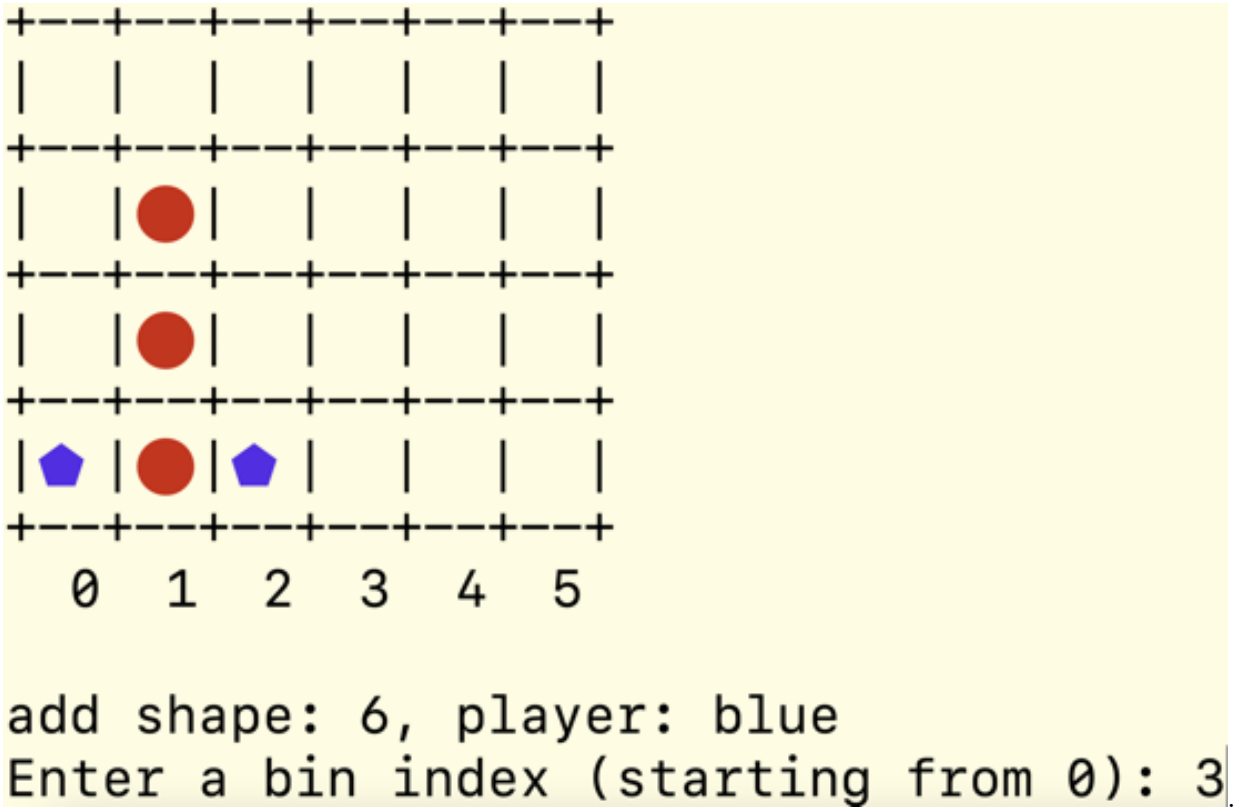
4. Enter 2 to put blue pentagon to bin 2.



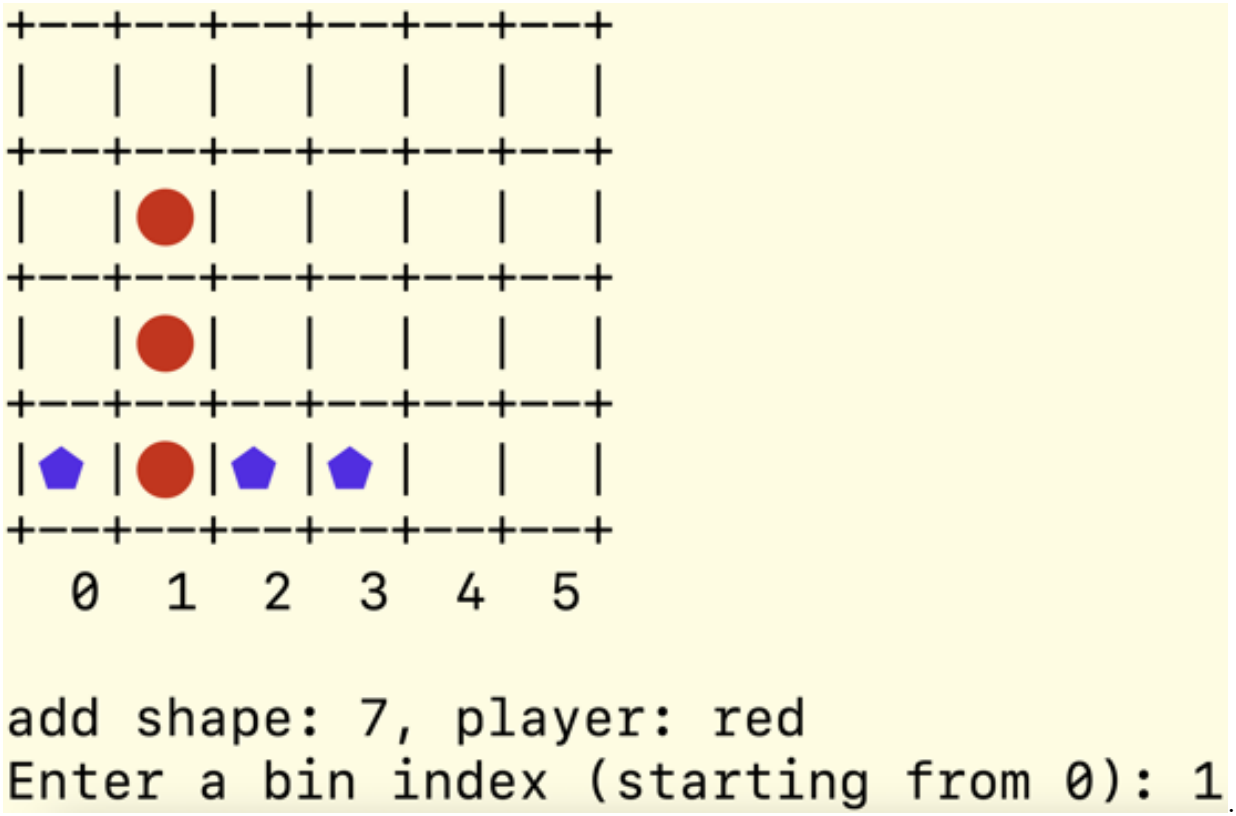
5. Enter 1 to put red circle to bin 1.



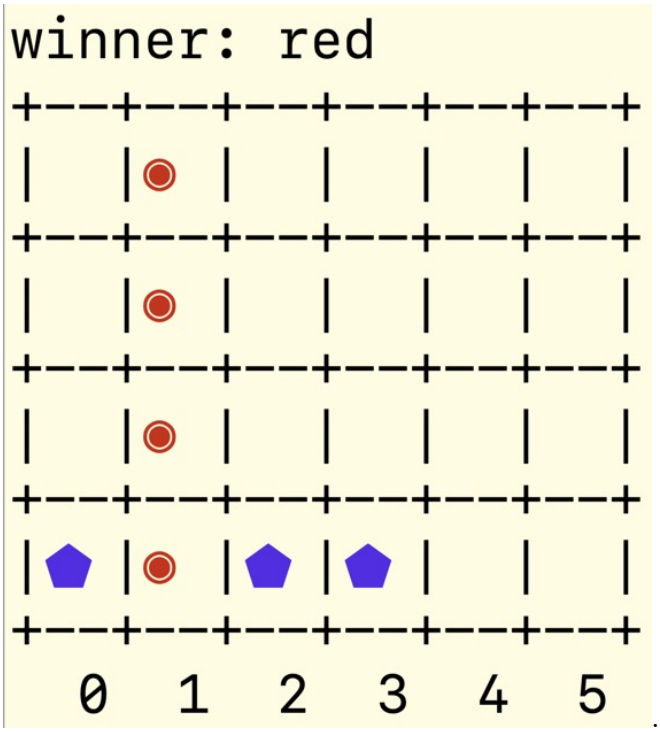
6. Enter 3 to put blue pentagon to bin 3.



7. Enter 1 to put red circle to bin 1.



8. The game ends. Declare the winner and show the consecutive elements.



6.3 Test play method of a non-default constructor

Run the following command to call `play` method of non-default Board object with 7 bins, each bin can hold at most 5 elements.

```
./test B
```

Once your code works fine in a local computer, upload `Board.cpp` to gradescope.

6.4 BoardTest.cpp

Create `BoardTest.cpp` with the following contents. The purpose of `BoardTest.cpp` is to test constructors and methods defined in `Board.cpp`.

```
#include "Board.hpp"
#include <iostream>
#include <string>
using namespace std;

int main() {
    //TODO: declare a Board object called game using its default constructor

    //TODO: call play method of Board object game.

    return 0;
}
```

Board.cpp concentrates on defining a Board objec while BoardTest.cpp focus on instantiating (aka, creating) a Board object and tests methods declared in Board.hpp.

6.5 makefile

Motivation: a large project may involve several files. We do not want to enter commands to compile and run each time. Also, we would like to re-compile or re-link only modified codes, not to re-compile or re-link each file.

Makefile comes to rescue.

6.6 Use makefile

For a large C++ project, it would better to use makefile, with which, only the modified source codes are recompiled and re-linked.

1. Edit a file called `makefile` with the following contents.

```
# This is an example Makefile for connect-4 project.
# This program uses Board and BoardTest modules.
# Typing 'make' or 'make run' will create the executable file.
#

# define some Makefile variables for the compiler and compiler flags
```

```
# to use Makefile variables later in the Makefile: $()
#
#  -g    adds debugging information to the executable file
#  -Wall turns on most, but not all, compiler warnings
#
# for C++ define  CC = g++
CC = g++ -std=c++11
#CFLAGS  = -g -Wall

# typing 'make' will invoke the first target entry in the file
# (in this case the default target entry)
# you can name this target entry anything, but "default" or "all"
# are the most commonly used names by convention
#
all: run

# To create the executable file connect4 (see -o connect4), we need the object
   files
# BoardTest.o and Board.o:
run:  BoardTest.o Board.o
    $(CC) -o connect4 BoardTest.o Board.o

# To create the object file BoardTest.o, we need the source
# files BoardTest.cpp, Competition.h
BoardTest.o:  BoardTest.cpp
    $(CC) -c BoardTest.cpp

# To create the object file Board.o, we need the source files
# Board.cpp.
# By default, $(CC) -c Board.cpp generates Board.o
Board.o:  Board.cpp
    $(CC) -c Board.cpp

# To start over from scratch, type 'make clean'.  This
# removes the executable file, as well as old .o object
# files and *~ backup files:
#
clean:
    $(RM) connect4 *.o *~
```

According to the command in this `makefile`,

`$(CC) -o connect4 BoardTest.o Board.o`

The generated runnable file is called `connect4`, which appears after `-o`.

2. Run make command.

   `make`

3. If there is no error in the above command, run the following command, where dot (.) means current directory.

   ```
   ./connect4
   ```

7 Common Mistakes for Task C

7.1 results.json file could not be parsed

```
./run_autograder: line 8:    15 Killed                  python3 run_tests.py > /
   autograder/results/results.json

Your results.json file could not be parsed as JSON. Its contents are as follows:
```

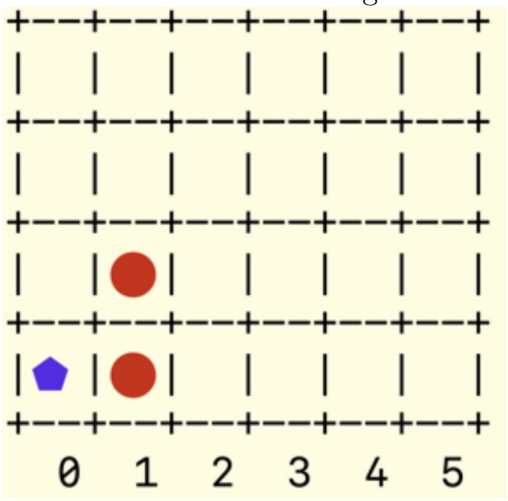
It is most likely your code has segmentation error – one reason is caused by out-of-boundary array index – and cannot generate output for the script to analyze.

Fix: test your code locally before uploading.

7.2 Segmentation Error

My code works in gradescope of Task B but has segmentation error in Task C when test locally or get 0 when uploading to gradescope.

Reason: the scripts in Task B only test a limited number of cases, and did not consider the case when the bins in the bottom left of the diagonal direction or the bottom right of the anti-diagonal direction, even the index itself is non-negative, may not be valid because that index may still be larger than the size of the other bin. The following is an example.



Suppose we add a red ball to the second bin, a blue ball to the first bin, and another ball to the second bin. The index of the most recent shape (the red ball on the top) in the second bin is 1. The ball on the bottom in the second bin has index 0.

In the anti-diagonal direction, when we check the bottom right direction, that is, move to the right bin, where bin index is 2, the index in the bottom right direction of the anti-digonal of the that bin is 0. Sound as a valid index in the second bin? NO. The second bin does not have any element yet.

1. In general, when moving down in diagonal or anti-diagonal direction, besides the index needs to be non-negative, it needs to be smaller than the size of the current bin, since the bin **changes**.

   Original:

```
//TODO (6) check the elements in the anti-diagonal direction
//bottom right to the last element of (bin)th bin.
//Find out all the consecutive VALID bottom right neighbors that share the same
   value as player

currBin = bin +1; //bin index of the first bottom right neighbor of {bin, idx}
currIdx = idx -1; //the index in bin of the first bottom right neighbor of {bin,
   idx}

while (currBin < numBins &&
       currIdx >= 0 && //Also NEED to check whether currIdx < grid[currBin]
       grid[currBin][currIdx] == player) {
    candidates.push_back({currBin, currIdx});

    //move to the next bottom right neighbor
    currBin++;
    currIdx--;
}
```

   Update:

```
//TODO (6) check the elements in the anti-diagonal direction
//bottom right to the last element of (bin)th bin.
//Find out all the consecutive VALID bottom right neighbors that share the same
   value as player

currBin = bin +1; //bin index of the first bottom right neighbor of {bin, idx}
currIdx = idx -1; //the index in bin of the first bottom right neighbor of {bin,
   idx}

while (currBin < numBins &&
       currIdx >= 0 &&
       currIdx < grid[currBin].size() &&
       grid[currBin][currIdx] == player) {
    candidates.push_back({currBin, currIdx});

    //move to the next bottom right neighbor
    currBin++;
    currIdx--;
}
```

   A thumb rule for using an array – a vector is also an array, just with methods associated with it – is to make sure that the index are valid, otherwise, index out of boundary exception happens, and result in segmentation errors.

Note that in the above code, the order of testing the index cannot be switched.

(a) `currBin < numBins` guarantees that bin index `currBin` is valid.

(b) Only when `currBin` is valid, can we use `grid[currBin].size()` as in the following conditions.

```
currIdx >= 0 &&
currIdx < grid[currBin].size()

```

It tests that currIdx, index of items in `grid[currBin]`, is valid or not. You may switch the order of the above two clauses – units of conditions – as in

`currIdx < grid[currBin].size() && currIdx >= 0`.

(c) Only both `currBin` and `currIdx` are valid, can we use `grid[currBin][currIdx]` as in

`grid[currBin][currIdx] == player`.

(d) Students may wonder when we move towards the top left direction of the anti-diagonal, do we need to check `currIdx >= 0` or not. That is, do we need to modify the following code?

```
//MOVING UPWARDS TOWARDS THE LEFT
//Find out all the VALID top left neighbors of (bin, idx) with the same value
int currBin = bin - 1;
int currIdx = idx + 1;

while (currBin >= 0 &&
       currIdx < grid[currBin].size() &&
       grid[currBin][currIdx] == player){
    candidates.push_back({currBin, currIdx});

    //Move to the next top left position
    currBin--;
    currIdx++;
}
```

The answer is no. Reason:

(e) `currIdx` starts from `idx + 1`, an index that is valid in (`bin`)th bin. Hence `currIdx` is larger than `idx`, a non-negative integers, so `currIdx` is definitely larger than 0.

(f) Thanks to the requirements of method `add`, only when a valid bin that is not full can be chosen, where not full means `idx < grid[bin].size()`. That is, we have

`idx >= 0` and `idx < grid[bin].size()`

(g) However, `idx < grid[bin].size()` cannot guarantee that

`idx < grid[currBin].size()`

since `bin` and `currBin` are indices of different bins, which may have different sizes.

(h) When coding, we need to be succinct, write only needed code. The more (unnecessary) codes we add, the hard to read and maintain the codes.

(i) What additional check we may need to do?

i. In `winInDiagonal` method, when working with the diagonal from the bottom left to the top right, when moving towards the bottom left direction, need to make sure that `currIdx < grid[currBin].size()`.

ii. In `winInHorizontal` method, when checking consecutive left or right sharing the same value as `player`, need to make sure that `currIdx < grid[currBin].size()`.
Explanation: when moving horizontally, `currIdx` is the same as `idx`, so it must be in `[0, grid[bin].size())`, a non-negative integer. However, `currIdx` is the index of (`currBin`)th bin, a different bin from (`bin`)th bin. So `currIdx` may not satisify `currIdx < grid[currBin].size()`.

iii. In `winInVertical` method, only need to check downwards direction since there is no shape on the top of the most recent added shape of the bin to be tested.

7.3 Method win

```
int Board::win(int bin){
    //Let winH be the return of winInHorizontal applying on bin.
    //Let winV be the return of winInVertical applying on bin.
    //Let winD be the return of winInDiagonal applying on bin.

    //if winH is not -1, return winH

    //if winV is not -1, return winV

    //if winD is not -1, return winD

    //return -1
}
```

The above code can be improved, we do not need to test wins in horizontal-, veritcal-, and diagonal-directions. If we find out the first winning direction, return it, otherwise, try another direction.

```
int Board::win(int bin){
    //(1) Let winH be the return of winInHorizontal applying on bin.
    //    if (winH is not -1), return winH.

    //Otherwise, winH returns -1, that means no win in horizontal direction.
    //(2) Let winV be the return of winInVertical applying on bin.
    //if (winV is not -1), return winV.

    //    Otherwise, winV returns -1, that means no win in vertical direction.
    //(3) Let winD be the return of winInDiagonal applying on bin.

    //(4) return winD, whether it is a player id or -1.
}
```

Warning: the following implementation is wrong.

```
int Board::win(int bin){
    if (winInHorizontal(bin) != -1)
       return winInHorizontal(bin);

    //omit the rest codes
}
```

In the first call of `winInHorizontal(bin)`, if there is a win, as the following,
`0 0 0 0 1 1 1`
To show the winning path, we increase 0 to be 2.
`2 2 2 2 1 1 1`.
In the second call of `winInHorizontal(bin)`, which shows a win as well. Increase 2 to be 4.
`4 4 4 4 1 1 1`.

However, a mapping in `display` method has only four mappings, where 0 is mapped to a red circle, 1 is mapped to a blue pentagon, 2 is mapped to a double red circle, and 3 is mapped to an empty blue pentagon. So index is at most 3 and 4 is not a valid index. There is an out-of-boundary exception and would result in segmentation error.

Also, calling a function involves overheads such as saving the local variables and return point of a caller, passing the values of actual parameters to formal parameters, taking return if necessary, and switching controls between a caller and a callee. We can save the return in a variable, thus to save calling the same function for more than once. This is called "trade memory for time efficiency".

7.4 Method play

In `play` method, need the following variables.

1. Variable `bin` indicates the bin index of the bin worked.
2. Variable `player` indicates the player id. It is initialized to be 0.
3. Variable `numAdded` indicates the number of shapes added to the grid so far. It is initialized to be 0.
4. Variable `winner` represents the id of the player who wins the game. It is initialized to be -1, indicating there is no winner found yet.

   Note, we could set a bool variable to indicate whether a winner is found or not. However, a bool variable has only true or false value, an integer can carry more values.

We continue to play the game as long as no winner is found and there is empty slots in the grid. In each round, we do the following.

1. Let the current player choose a bin.
2. Test whether the current move leads to a win or not.
3. Display the current grid.
4. Let the other player plays.

```
void Board::play(){
    //TODO: Display an empty grid (no element in any cell). Which method should be call
    ?


    //TODO: declare bin to be an int.


    //TODO: declare player to be an int,
    //      representing the id of the current player.
    //      player is initialized to be 0.

    //TODO: declare numAdded to count the number of shapes
    //      added to the board.


    //TODO: declare winner to be an integer, initialized to be -1.


    //Keep doing the following until either a winner is found or every cell in the grid
    is filled.
    while(winner is not found and not all cells in the grid is filled){
        //TODO: let player choose which bin to add an element.
        //      Which method to call?
        //      Put the return to variable bin.


        //TODO: test whether there is a win or not.
        //      Which method to call? Which parameter to pass?
        //      Put the return to variable winner.

        //TODO: increase number of shapes added to the grid by 1.


        //TODO: call display method again to illustrate
        //      the current status of the grid.

        //TODO: move to the next player.
        //      You can either use
        //      (a) if-else statement, OR
        //      (b) exclaimation operator (!),
        //          which converts 1 to 0 and 0 to 1. OR
        //      (c) subtract player from 1.
        //          If player is 0, then 1 - player is 1.
        //          Otherwise, player must be 1 in this example,
        //          then 1 - player is 0.
```

```
45
46      }
47
48      //TODO: Once we are out of the above loop,
49      //      (1) either a winner is found, depending on
50      //          the value of winner variable,
51      //          print "winner: red" or "winner: blue"
52      //      OR
53      //      (2) all cells are filled and no one wins.
54      //          In that situation, print "a tie".
55
56
57  }
```

A common mistake is, when a winner is found, not to show the winner path immediately. To fix it, display method is called only once AFTER calling win method, which set the elements along the winning path if a winner is found.

Remember: write succinct codes, do not include any unnecessary code.

Also, verify an index is valid first BEFORE using it to get the element in the corresponding a.

For example,

```
1  //Suppose that currBin is properly declared and initialized.
2  //Assume that currBin is a non-negative int.
3
4  //Suppose currIdx is properly declared and initialized.
5  if (grid[currBin][currIdx] == player &&
6      currBin < numBins && //Assume that currBin >= 0 already,
7                           //so no need to check this condition again
8      currIdx >= 0 && currIdx < grid[currBin].size())
9      ...
```

The above code is WRONG. The condition is analyzed from left to right. Suppose currBin is 0, numBins is 6. Assume that `grid[currBin]` has only 1 element, so `grid[currBin].size()` returns 1. Suppose `currIdx` is 2.

By the above code, before the rest condition can be checked, `grid[currBin][currIdx]` runs and results in out-of-boundary exception since `currIdx` is larger than `grid[currBin].size()`.