Formal Modeling of a Tetris Game

Mestrado Integrado em Engenharia Informática e Computação

Métodos Formais em Engenharia de Software

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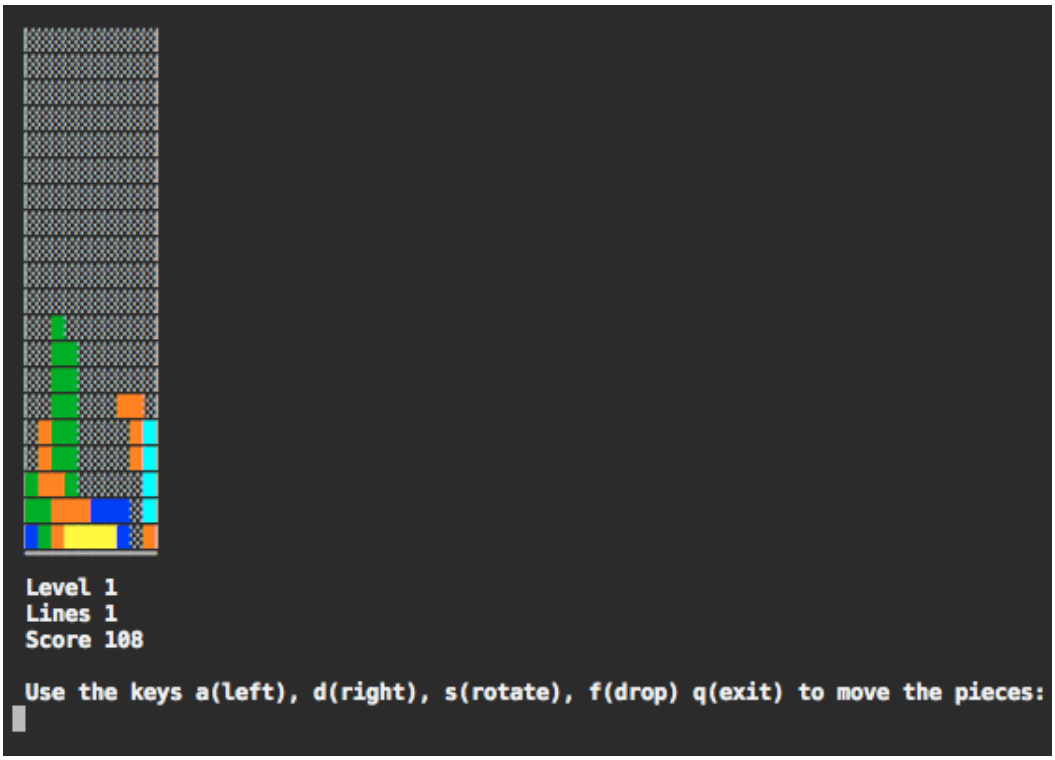
1 Informal System Description and List of Requirements

1.1 Informal System Description

Tetris is a puzzle game and one of the most recognizable and influential video game brands in the world. It is no wonder why there are hundreds of millions of Tetris products being played, worn, and enjoyed by fans in their everyday lives. The game was born in 1984 and it is living proof of a game that has truly transcended the barriers of culture and language.

A meritorious reference to Alexey Pajitnov because he is the person who developed this popular game. He is a Russian video game designer and computer engineer and in his spare time, he drew inspiration from his favorite puzzle board game, pentominoes, and decided to create a computer game for himself. Pajitnov envisioned an electronic game that let players arrange puzzle pieces in real time as they fell from the top of the playing field. The resulting design was a game that used seven distinctive geometric playing pieces (appendixB), each made up of four squares. Pajitnov called this game "Tetris," a combination of "tetra" (the Greek word meaning "four") and "tennis" (his favorite sport).

The rules to play the game are very simple. The players are required to strategically rotate and drop a chaining of tetraminoes that fall into the rectangular board at increasing speeds. Players attempt to clear as many lines as possible by completing horizontal rows of blocks without empty space, but if the tetraminoes surpass the sky-line(top of the board) the game is over! Speed and consequent level advance can make the game ally to strategy more enthusiastic. Formal details about other rules are presented in appendixA.



1.2 List of Requirements

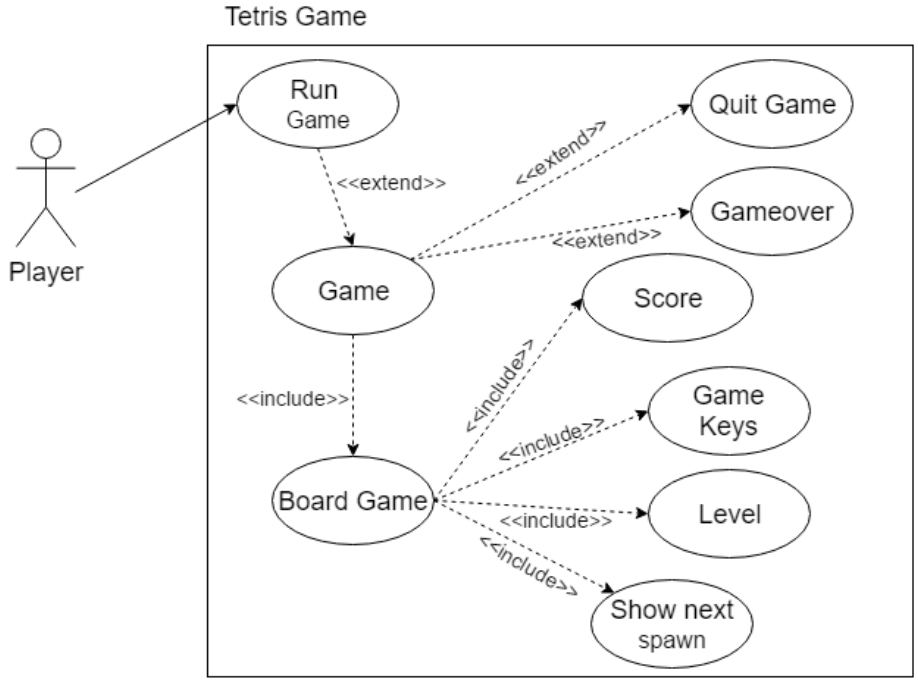
Id	Priority	Description
R1	Mandatory	The player can view his score and level
R2	Mandatory	The game allows five movements - rotation, left, right, down and drop
R3	Opcional	The player should be able to leave the game when he wants
R4	Mandatory	The player has access to a footnote where the rules to play the game are displayed
R5	Mandatory	The tetraminoes are spawned in a random order to be played
R6	Mandatory	When one or more rows are full of blocks they must be cleared
R7	Mandatory	If tetraminoes surpass the skyline the game is over
R8	Opcional	Time to time the level advances and the game becomes more difficult
R9	Mandatory	Each tetramino is formed by four squares named minoes

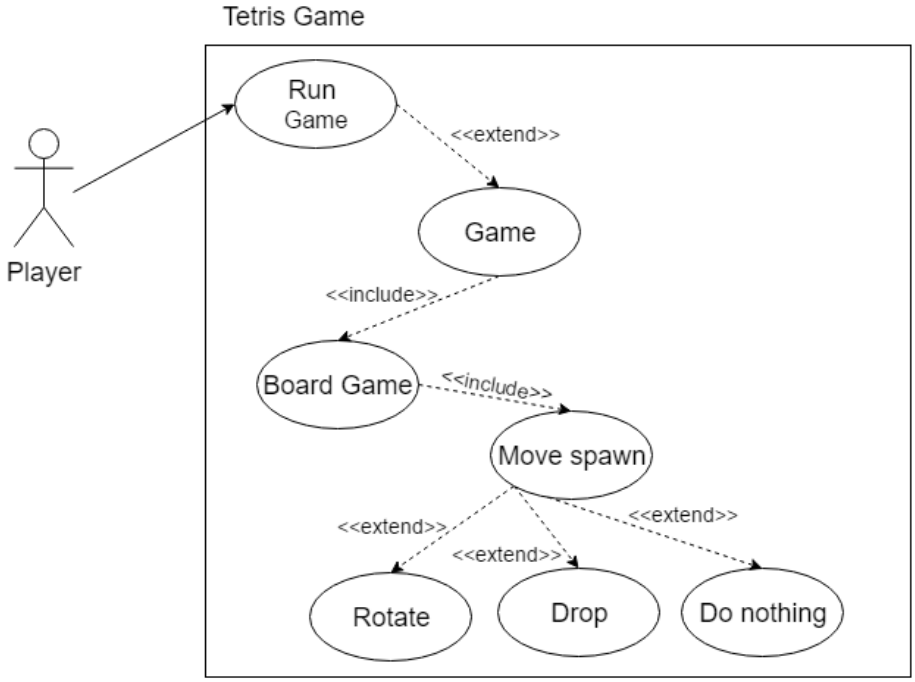
These requirements are directly translated onto use cases as shown next.

2 Visual UML Model

2.1 Use Case Model

In all use cases we have made an assumption that all keyboard game keys are functioning properly.





The main use cases are described below:

Scenario	**View Board Game**
Description	The player can see his actual difficulty level, score, keys to play the game and the next spawn
Pre-conditions	The game is running
Post-conditions	The player can view the information updated according to his performance during the game
Steps	(none)
Exceptions	(none)

Scenario	**Gameover**
Description	The player will finish the game
Pre-conditions	The game is running
Post-conditions	Game will reach the end and close
Steps	1. Play the game pressing the right keys 2. Update score and level 3. The game will eventually reach the end - gameover
Exceptions	(none)

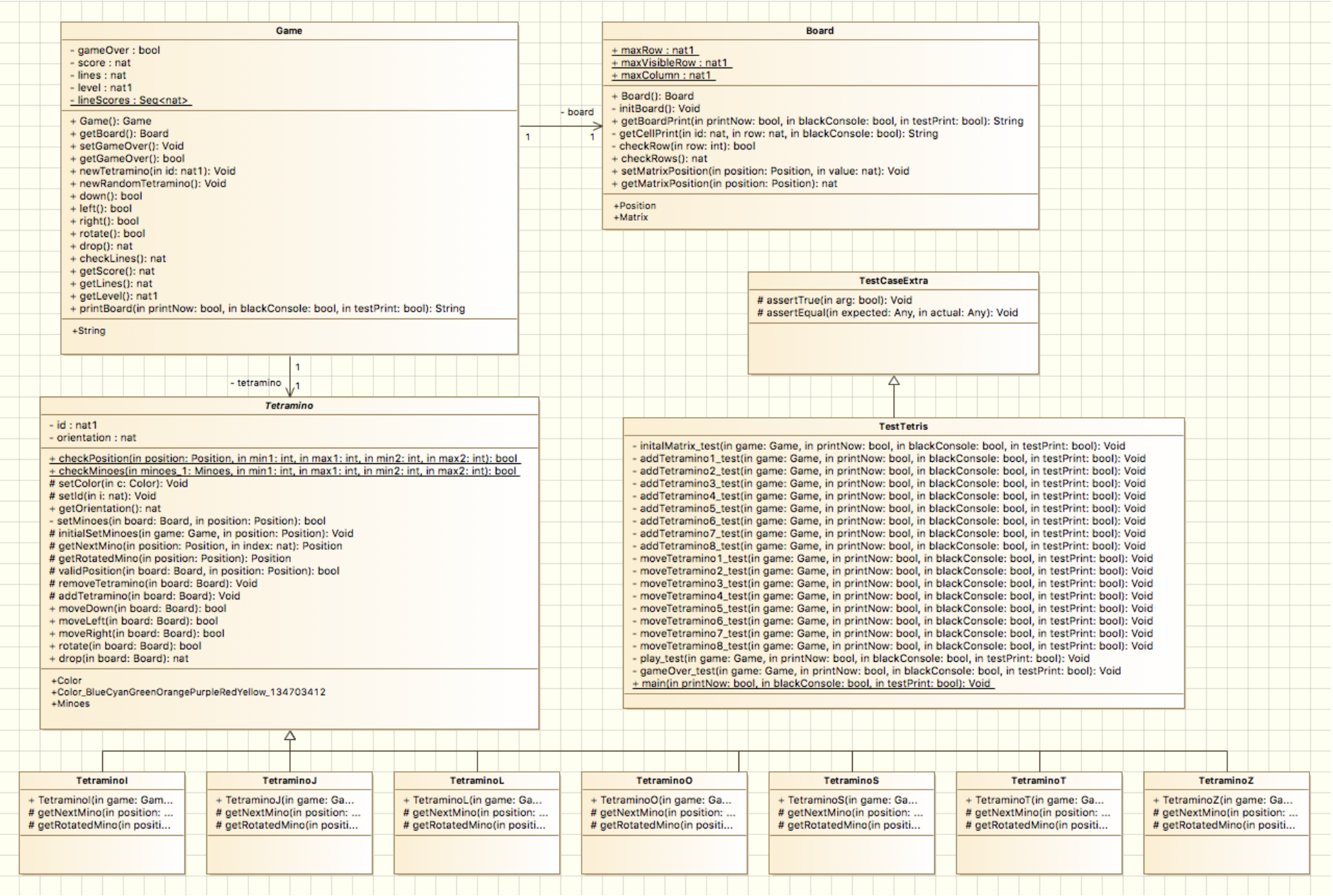
Scenario	**Rotation Move**
Description	Rotate a tetramino when is falling
Pre-conditions	Tetramino must not be frozen in place
Post-conditions	Tetramino position has changed
Steps	The player must click on a key that allows rotation
Exceptions	When, simultaneously, try to rotate and the spawn reached one final position or the skyline pf the board

Scenario	**Drop Move**
Description	Accelerates the tetramino falling and position it as it was before reach the final position
Pre-conditions	Tetramino must not be frozen in place
Post-conditions	Tetramino position has changed
Steps	The player must click on a key that allows falling spawn
Exceptions	(none)

2.2 Class Model

Class	**Description**
Game	Core model; defines the state variables and operations available to the players
Board	Defines a game environment for playing and where each piece of tetraminoes can stay
Tetramino	Defines one general piece to play with
TetraminoI/J/L/O/S/T/Z	Defines one specific piece and is a subclass of Tetramino
TestCaseExtra	Superclass for test classes; defines assertEquals and assertTrue
TestTetris	Defines the test/usage scenarios and test cases for the tetris game

Table 1: Description of each class


Game
- gameOver : bool
- score : nat
- lines : nat
- level : nat1
- lineScores : Seq<nat>
+ Game(): Game
+ getBoard(): Board
+ setGameOver(): Void
+ getGameOver(): bool
+ newTetramino(in id: nat1): Void
+ newRandomTetramino(): Void
+ down(): bool
+ left(): bool
+ right(): bool
+ rotate(): bool
+ drop(): nat
+ checkLines(): nat
+ getScore(): nat
+ getLines(): nat
+ getLevel(): nat1
+ printBoard(in printNow: bool, in blackConsole: bool, in testPrint: bool): String
+String
- board
1
1
Board
+ maxRow : nat1
+ maxVisibleRow : nat1
+ maxColumn : nat1
+ Board(): Board
- initBoard(): Void
+ getBoardPrint(in printNow: bool, in blackConsole: bool, in testPrint: bool): String
- getCellPrint(in id: nat, in row: nat, in blackConsole: bool): String
- checkRow(in row: int): bool
+ checkRows(): nat
+ setMatrixPosition(in position: Position, in value: nat): Void
+ getMatrixPosition(in position: Position): nat
+Position
+Matrix
TestCaseExtra
assertTrue(in arg: bool): Void
assertEqual(in expected: Any, in actual: Any): Void
- tetramino
1
1
Tetramino
- id : nat1
- orientation : nat
+ checkPosition(in position: Position, in min1: int, in max1: int, in min2: int, in max2: int): bool
+ checkMinoes(in minoes_1: Minoes, in min1: int, in max1: int, in min2: int, in max2: int): bool
# setColor(in c: Color): Void
# setId(in i: nat): Void
+ getOrientation(): nat
- setMinoes(in board: Board, in position: Position): bool
initialSetMinoes(in game: Game, in position: Position): Void
getNextMino(in position: Position, in index: nat): Position
getRotatedMino(in position: Position): Position
validPosition(in board: Board, in position: Position): bool
removeTetramino(in board: Board): Void
addTetramino(in board: Board): Void
+ moveDown(in board: Board): bool
+ moveLeft(in board: Board): bool
+ moveRight(in board: Board): bool
+ rotate(in board: Board): bool
+ drop(in board: Board): nat
+Color
+Color_BlueCyanGreenOrangePurpleRedYellow_134703412
+Minoes
TestTetris
- initalMatrix_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- addTetramino1_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- addTetramino2_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- addTetramino3_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- addTetramino4_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- addTetramino5_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- addTetramino6_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- addTetramino7_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- addTetramino8_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- moveTetramino1_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- moveTetramino2_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- moveTetramino3_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- moveTetramino4_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- moveTetramino5_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- moveTetramino6_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- moveTetramino7_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- moveTetramino8_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- play_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
- gameOver_test(in game: Game, in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
+ main(in printNow: bool, in blackConsole: bool, in testPrint: bool): Void
TetraminoI
+ TetraminoI(in game: Gam...
# getNextMino(in position: ...
# getRotatedMino(in positi...
TetraminoJ
+ TetraminoJ(in game: Ga...
# getNextMino(in position: ...
# getRotatedMino(in positi...
TetraminoL
+ TetraminoL(in game: Ga...
# getNextMino(in position: ...
# getRotatedMino(in positi...
TetraminoO
+ TetraminoO(in game: Ga...
# getNextMino(in position: ...
# getRotatedMino(in positi...
TetraminoS
+ TetraminoS(in game: Ga...
# getNextMino(in position: ...
# getRotatedMino(in positi...
TetraminoT
+ TetraminoT(in game: Ga...
# getNextMino(in position: ...
# getRotatedMino(in positi...
TetraminoZ
+ TetraminoZ(in game: Ga...
# getNextMino(in position: ...
# getRotatedMino(in positi...

3 Formal VDM++ Model

3.1 Game

```
class Game

 -- Represents the whole game, and provides all the necessary
 -- operations for playing it.


 types

  public String = seq of char;


 instance variables

  -- The game board.
  private board  : Board;
  -- The current game tetramino.
  private tetramino : Tetramino;
  -- Indicates if the game is finished.
  private gameOver : bool   := false;
  -- The game score.
  private score  : nat   := 0;
  -- The number of completed lines in the game.
  private lines  : nat   := 0;
  -- The level of the game.
  private level  : nat1   := 1;

  -- The scores that lines make, according to the number of lines
  -- made at once (1, 2, 3 or 4).
  private static lineScores : seq of nat
   := [100, 300, 400, 800];


 operations

  public Game : () ==> Game

  Game() ==
   board := new Board();

    public getBoard: () ==> Board

    getBoard() ==
     return board;

  public setGameOver : () ==> ()

  setGameOver() ==
   gameOver := true;

  public getGameOver : () ==> bool

  getGameOver() ==
   return gameOver;

    -- Generates a new tetramino of the specified type.
  public newTetramino : nat1 ==> ()

  newTetramino(id) == (
   cases id:
```

```
    1 -> tetramino := new TetraminoI(self),
    2 -> tetramino := new TetraminoJ(self),
    3 -> tetramino := new TetraminoL(self),
    4 -> tetramino := new TetraminoO(self),
    5 -> tetramino := new TetraminoS(self),
    6 -> tetramino := new TetraminoT(self),
    7 -> tetramino := new TetraminoZ(self)
   end;
  )
  pre id >= 1 and id <= 7;

    -- Generates a new random tetramino.
  public newRandomTetramino: () ==> ()

  newRandomTetramino() ==
   newTetramino(MATH`rand(7) + 1);

    -- Tries to move the current tetramino down.
  public down : () ==> bool

  down() ==
   return tetramino.moveDown(board);

    -- Tries to move the current tetramino left.
  public left : () ==> bool

  left() ==
   return tetramino.moveLeft(board);

    -- Tries to move the current tetramino right.
  public right : () ==> bool

  right() ==
   return tetramino.moveRight(board);

    -- Tries to rotate the current tetramino.
  public rotate : () ==> bool

  rotate() ==
   return tetramino.rotate(board);

    -- Drops the current tetramino to the bottom of the board.
    -- Also updates the score, using the current level and the
    -- total distance of the drop.
  public drop : () ==> nat

  drop() == (
   dcl dropDistance: nat := tetramino.drop(board);
   score := score + dropDistance * level;
   return dropDistance;
  );

  -- Checks all game lines for completion and updates the game
  -- score according to the number of completed lines and the
  -- current game level.
  public checkLines : () ==> nat

  checkLines() == (
   dcl newLines: nat := board.checkRows();
   lines := lines + newLines;
   if newLines > 0 then score := score + lineScores(newLines) * level;
   level := 1 + (lines div 10);
   return newLines
  );
```

```
  public getScore : () ==> nat

  getScore() == return score;

  public getLines : () ==> nat

  getLines() == return lines;

  public getLevel : () ==> nat1

  getLevel() == return level;

  -- Returns a printing string of the board.
  -- If blackConsole is true, there are only three strings
  -- possible, depending on whether the position is empty or filled
  -- and diferentiating the invisible lines.
  -- If blackConsole is false, each tetramino will have a different
  -- print, according to its color.
  public printBoard : bool * bool * bool ==> String

  printBoard(printNow, blackConsole, testPrint) ==
   return board.getBoardPrint(printNow, blackConsole, testPrint);

end Game
```

3.2 Board

```
class Board

 -- Represents the game board, with its matrix.


 types

  -- Position in the board.
  public Position = seq of int
  -- A position is a sequence with exactly to integers.
  inv position == len position = 2;
  -- The board matrix is represented by a map.
  public Matrix = map Position to nat;


 instance variables

  -- Total number of rows in the board, including two lines that
  -- are not displayed for the user to see.
  public static maxRow  : nat1   := 22;
  -- Total number of rows that are visible during gameplay.
  public static maxVisibleRow : nat1   := 20;
  -- Total number of columns in the board.
  public static maxColumn  : nat1   := 10;

  -- Aids for printing the board matrix in the console.
  private print_startTag  : Game`String := "|";
  private print_endTag  : Game`String := "|\n";
  private print_bottomLine : Game`String := " ----------";

  -- The matrix attributes to each position in the board
  -- a natural number: 0 if the position is empty; the id of the
  -- tetramino if it is occupied.
  private matrix     : Matrix  := {|->};
```

```
operations

 public Board : () ==> Board

 Board() == (
  initBoard();
 );

 -- Initiates the board matrix with all positions empty,
 -- that is, with zeros.
 private initBoard : () ==> ()

 initBoard() == (
  for i = 1 to maxRow do
   for j = 1 to maxColumn do
    matrix := matrix ++ {[i,j] |-> 0}
 )
 post matrix([1,1]) = 0 and matrix([maxRow, maxColumn]) = 0;

 -- Returns a string containing the board matrix in its
 -- printing form. If the boolean printNow is true, the matrix is
 -- immediately printed. If the boolean blackConsole is true, the
 -- matrix is printed without using colors. If the boolean testPrint
 -- is true, the invisible lines are printed for test purposes.
 public getBoardPrint : bool * bool * bool ==> Game`String

 getBoardPrint(printNow, blackConsole, testPrint) == (
  dcl print_board : Game`String := "\n";
  dcl start_row : nat1 := 3;
  if testPrint then start_row := 1;
  for i = start_row to maxRow do(
   print_board := print_board ^ print_startTag;
     for j=1 to maxColumn do
      print_board := print_board
       ^ getCellPrint(matrix([i,j]), i, blackConsole);
     print_board := print_board ^  print_endTag;
    );
    if printNow then
     IO`println(print_board ^ print_bottomLine);
   return print_board ^ print_bottomLine ;
 );

 -- Returns the string corresponding to a board cell print.
 -- If blackConsole is true, there are only three strings
 -- possible, depending on whether the position is empty or filled
 -- and diferentiating the invisible lines.
 -- If blackConsole is false, each tetramino will have a different
 -- print, according to its color.
 private getCellPrint: nat * nat * bool ==> Game`String

 getCellPrint(id, row, blackConsole) == (
  if blackConsole then
   cases id:
    0 -> if row < 3 then return " " else return "#",
    others -> return "*"
   end
  else
   cases id:
    0 -> if row < 3 then return " " else return "#",
    1 -> return "\u001B[38;5;51m" ^ "*" ^ "\u001B[0m",
    2 -> return "\u001B[38;5;21m" ^ "*" ^ "\u001B[0m",
    3 -> return "\u001B[38;5;208m" ^ "*" ^ "\u001B[0m",
    4 -> return "\u001B[38;5;226m" ^ "*" ^ "\u001B[0m",
```

```
    5 -> return "\u001B[38;5;34m" ^ "*" ^ "\u001B[0m",
    6 -> return "\u001B[38;5;165m" ^ "*" ^ "\u001B[0m",
    others -> return "\u001B[38;5;196m" ^ "*" ^ "\u001B[0m"
   end
);

-- Checks a board row to determine if it is completely filled
-- with tetramino cells. In affirmative case, the row is removed
-- from the board and the rows above it are shifted down.
private checkRow : int ==> bool

checkRow(row) == (
 for column = 1 to maxColumn do
  if (matrix([row, column]) = 0) then return false;
 for i = row - 1 to 1 by -1 do
  for j = 1 to maxColumn do
   matrix([i + 1, j]) := matrix([i, j]);
 return true
)
pre row >= 1 and row <= maxRow;

-- Checks all the rows of the board and returns the number of rows
-- that where removed.
public checkRows : () ==> nat

checkRows() == (
 dcl result : nat := 0;
 for row = 1 to maxRow do
  if checkRow(row) then result := result + 1;
 return result
)
post RESULT <= maxRow;

public setMatrixPosition : Position * nat ==> ()

setMatrixPosition(position, value) ==
 matrix(position) := value
pre Tetramino`checkPosition(position, 1, maxRow, 1, maxColumn);

public getMatrixPosition : Position ==> nat

getMatrixPosition(position) ==
 return matrix(position)
pre Tetramino`checkPosition(position, 1, maxRow, 1, maxColumn);

end Board
```

3.3 Tetramino

```
class Tetramino

-- Defines a tetris piece, with all its relevant attributes.
-- The position of the tetramino is represented by the position of
-- its minoes, which are the four cells composing the tetramino.


types

 public Color = <Cyan> | <Blue> | <Orange>
  | <Yellow> | <Green> | <Purple> | <Red>;
 public Minoes = seq of Board`Position
```

```
 -- There are always 4 minoes in each tetramino.
 inv minoes == len minoes = 4


instance variables

 -- Color of the piece, to aid in visualization
 private color  : Color  := <Cyan>;
 -- Id of the piece, to simplify its representation in the board
 private id   : nat1   := 1;
 -- The current orientation of the tetramino, since it can rotate
 private orientation : nat   := 0;
 -- The positions of each of the individual cells of the tetramino
 private minoes  : Minoes := [[1, 1], [1, 2], [1, 3], [1, 4]];

 -- The id is a natural number between 1 and 7,
 -- because there are 7 different types of tetraminoes
 -- The orientation is a number between 0 and 3,
 -- because there are at most 4 different orientations,
 -- depending on the tetramino type.
 inv id <= 7 and orientation < 4


functions

 -- Checks if a given position is contained within the expected parameters.
 public checkPosition : Board`Position * int * int * int * int -> bool

 checkPosition(position, min1, max1, min2, max2) ==
  position(1) >= min1
  and position(1) <= max1
  and position(2) >= min2
  and position(2) <= max2;

 -- Checks that all the tetramino cells have different positions,
 -- and that those positions are inside the expected parameters,
 -- which will be the board limits
 public checkMinoes: Minoes * int * int * int * int -> bool

 checkMinoes(minoes, min1, max1, min2, max2) ==
  card elems minoes = 4
  and forall mino in set elems minoes &
   checkPosition(mino, min1, max1, min2, max2)


operations

 protected setColor : Color ==> ()

 setColor(c) == color := c;

 protected setId : nat ==> ()

 setId(i) == id := i
 pre i >= 1 and i <= 7;

 public getOrientation : () ==> nat

 getOrientation() == return orientation
 post RESULT < 4;

 -- Given the position of the first of the four minoes, this operation
 -- sets the position of remaining three minoes. It also places the tetramino
 -- on the board if all positions are valid, otherwise, the tetramino remains
 -- in its original position.
```

```
private setMinoes : Board * Board`Position ==> bool

setMinoes(board, position) == (
 dcl tempMinoes : Minoes := minoes;
 dcl tempPosition : Board`Position := position;
 removeTetramino(board);
 for i = 1 to 4 do (
  if (validPosition(board, tempPosition))
  then tempMinoes(i) := tempPosition
  else (
   addTetramino(board);
   return false
  );
  tempPosition := getNextMino(tempPosition, i);
 );
 minoes := tempMinoes;
 addTetramino(board);
 return true
)
pre checkPosition(position, -1, Board`maxRow + 2, -1, Board`maxColumn + 2)
post checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn);

-- Very similar to the previous operation, but this one is used only when a
-- tetramino is generated. It does not remove the tetramino from its previous
-- position on the board (since it was never placed) and if at least one of the
-- positions of the minoes is invalid, it declares the game over.
protected initialSetMinoes : Game * Board`Position ==> ()

initialSetMinoes(game, position) == (
 dcl tempPosition : Board`Position := position;
 dcl tempMinoes : Minoes := minoes;
 for i = 1 to 4 do (
  if (validPosition(game.getBoard(), tempPosition))
  then (
   tempMinoes(i) := tempPosition;
   tempPosition := getNextMino(tempPosition, i)
  )
  else game.setGameOver()
 );
 if not game.getGameOver() then (
  minoes := tempMinoes;
  addTetramino(game.getBoard())
 )
)
pre checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
post checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn);

-- Given the position of one mino it computes the position of the next mino
-- in the tetramino. The current mino is identified by its index within the
-- tetramino. This is highly dependent on the type of tetramino, so can
-- only be defined in each subclass.
protected getNextMino: Board`Position * nat ==> Board`Position

getNextMino(position, index) ==
 is subclass responsibility;

-- Given the current position of the first mino of a tetramino, determines
-- the position of that mino after the tetramino is rotated.
protected getRotatedMino: Board`Position ==> Board`Position

getRotatedMino(position) ==
 is subclass responsibility;

-- Checks if a given position on the board is valid for occupation, that is,
-- if it is inside the board limits and not currently occupied by some mino
```

```
protected validPosition : Board * Board`Position ==> bool

validPosition(board, position) ==
 return checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
  and board.getMatrixPosition(position) = 0;

-- Removes the tetramino from the board.
protected removeTetramino : Board ==> ()

removeTetramino(board) ==
 for mino in minoes do
  board.setMatrixPosition(mino, 0)
pre checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn);

-- Places the tetramino in the board.
protected addTetramino : Board ==> ()

addTetramino(board) ==
 for mino in minoes do
  board.setMatrixPosition(mino, id)
pre checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn);

-- Moves the tetramino down in the board.
public moveDown : Board ==> bool

moveDown(board) ==
 return setMinoes(board, [minoes(1)(1) + 1, minoes(1)(2)])
pre checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn)
post checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn);

-- Moves the tetramino left in the board.
public moveLeft : Board ==> bool

moveLeft(board) ==
 return setMinoes(board, [minoes(1)(1), minoes(1)(2) - 1])
pre checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn)
post checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn);

-- Moves the tetramino right in the board.
public moveRight : Board ==> bool

moveRight(board) ==
 return setMinoes(board, [minoes(1)(1), minoes(1)(2) + 1])
pre checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn)
post checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn);

-- Rotates the tetramino in the board.
public rotate : Board ==> bool

rotate(board) == (
 dcl position : Board`Position := getRotatedMino(minoes(1));
 orientation := (orientation + 1) mod 4;
 return setMinoes(board, position)
)
pre checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn)
post checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn);

-- Drops the tetramino to the lowest available position in the board.
public drop : Board ==> nat

drop(board) == (
 dcl result : nat := 0;
 while moveDown(board) do
  result := result + 1;
 return result
```

```
  )
  pre checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn)
  post checkMinoes(minoes, 1, Board`maxRow, 1, Board`maxColumn)
   and RESULT < Board`maxRow;

end Tetramino
```

3.4 TetraminoI

```
class TetraminoI is subclass of Tetramino

 -- Tetramino of the type I: xxxx
 --
 --
 -- Minoes:         1234
 --


 operations

  public TetraminoI : Game ==> TetraminoI

  TetraminoI(game) == (
   Tetramino`setColor(<Cyan>);
   Tetramino`setId(1);
   Tetramino`initialSetMinoes(game, [2, 4]);
   return self
  );

  protected getNextMino: Board`Position * nat ==> Board`Position

  getNextMino(position, index) == (
   dcl result : Board`Position := position;
   cases Tetramino`getOrientation():
    0 -> result(2) := position(2) + 1,
    1 -> result(1) := position(1) + 1,
    2 -> result(2) := position(2) - 1,
    3 -> result(1) := position(1) - 1
   end;
   return result
  )
  pre Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
  post Tetramino`checkPosition(RESULT, 0, Board`maxRow + 1, 0, Board`maxColumn + 1);

  protected getRotatedMino: Board`Position ==> Board`Position

  getRotatedMino(position) == (
   dcl result : Board`Position := position;
   cases Tetramino`getOrientation():
    0 -> (
     result(1) := position(1) - 1;
     result(2) := position(2) + 2;
     ),
    1 -> (
     result(1) := position(1) + 2;
     result(2) := position(2) + 1;
     ),
    2 -> (
     result(1) := position(1) + 1;
     result(2) := position(2) - 2;
     ),
```

```
    3 -> (
     result(1) := position(1) - 2;
     result(2) := position(2) - 1;
     )
   end;
   return result
  )
  pre Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
  post Tetramino`checkPosition(RESULT, -1, Board`maxRow + 2, -1, Board`maxColumn + 2);


end TetraminoI
```

3.5 TetraminoJ

```
class TetraminoJ is subclass of Tetramino

 -- Tetramino of the type J: x
 --       xxx
 --
 -- Minoes:       1
 --        234


 operations

  public TetraminoJ : (Game) ==> TetraminoJ
  TetraminoJ(game) == (
   Tetramino`setColor(<Blue>);

   Tetramino`setId(2);
   Tetramino`initialSetMinoes(game, [1, 4]);
   return self
  );

  protected getNextMino: Board`Position * nat ==> Board`Position
  getNextMino(position, index) == (
   dcl result : Board`Position := position;

   cases Tetramino`getOrientation():
    0 -> (
     cases index:
      1 -> result(1) := position(1) + 1,
      others -> result(2) := position(2) + 1
     end
    ),
    1 -> (
     cases index:
      1 -> result(2) := position(2) - 1,
      others -> result(1) := position(1) + 1
     end
    ),
    2 -> (
     cases index:
      1 -> result(1) := position(1) - 1,
      others -> result(2) := position(2) - 1
     end
    ),
    3 -> (
     cases index:
      1 -> result(2) := position(2) + 1,
```

```
      others -> result(1) := position(1) - 1
     end
    )
   end;
   return result
  )
  pre index in set {1, ..., 4}
   and Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
  post Tetramino`checkPosition(RESULT, 0, Board`maxRow + 1, 0, Board`maxColumn + 1);

  protected getRotatedMino: Board`Position ==> Board`Position
  getRotatedMino(position) == (
   dcl result : Board`Position := position;

   cases Tetramino`getOrientation():
    0 -> result(2) := position(2) + 2,
    1 -> result(1) := position(1) + 2,
    2 -> result(2) := position(2) - 2,
    3 -> result(1) := position(1) - 2
   end;
   return result
  )
  pre Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
  post Tetramino`checkPosition(RESULT, -1, Board`maxRow + 2, -1, Board`maxColumn + 2);

end TetraminoJ
```

3.6 TetraminoL

```
class TetraminoL is subclass of Tetramino

 -- Tetramino of the type J: x
 --       xxx
 --
 -- Minoes:         1
 --         432


 operations

  public TetraminoL : (Game) ==> TetraminoL
  TetraminoL(game) == (
   Tetramino`setColor(<Orange>);

   Tetramino`setId(3);
   Tetramino`initialSetMinoes(game, [1, 6]);
   return self
  );

  protected getNextMino: Board`Position * nat ==> Board`Position
  getNextMino(position, index) == (
   dcl result : Board`Position := position;

   cases Tetramino`getOrientation():
    0 -> (
     cases index:
      1 -> result(1) := position(1) + 1,
      others -> result(2) := position(2) - 1
     end
    ),
    1 -> (
```

```
    cases index:
     1 -> result(2) := position(2) - 1,
     others -> result(1) := position(1) - 1
    end
   ),
   2 -> (
    cases index:
     1 -> result(1) := position(1) - 1,
     others -> result(2) := position(2) + 1
    end
   ),
   3 -> (
    cases index:
     1 -> result(2) := position(2) + 1,
     others -> result(1) := position(1) + 1
    end
   )
  end;
  return result
 )
 pre index in set {1, ..., 4}
  and Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
 post Tetramino`checkPosition(RESULT, 0, Board`maxRow + 1, 0, Board`maxColumn + 1);

 protected getRotatedMino: Board`Position ==> Board`Position
 getRotatedMino(position) == (
  dcl result : Board`Position := position;
  cases Tetramino`getOrientation():

   0 -> result(1) := position(1) + 2,
   1 -> result(2) := position(2) - 2,
   2 -> result(1) := position(1) - 2,
   3 -> result(2) := position(2) + 2
  end;
  return result
 )
 pre Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
 post Tetramino`checkPosition(RESULT, -1, Board`maxRow + 2, -1, Board`maxColumn + 2);

end TetraminoL
```

3.7 TetraminoO

```
class TetraminoO is subclass of Tetramino

 -- Tetramino of the type J: xx
 --          xx
 --
 -- Minoes:       12
 --          43


 operations
  public TetraminoO : (Game) ==> TetraminoO
  TetraminoO(game) == (
   Tetramino`setColor(<Yellow>);

   Tetramino`setId(4);
   Tetramino`initialSetMinoes(game, [1, 5]);
   return self
  );
```

```
  protected getNextMino: Board`Position * nat ==> Board`Position
  getNextMino(position, index) == (
   dcl result : Board`Position := position;

   cases Tetramino`getOrientation():
    0 -> (
     cases index:
      1 -> result(2) := position(2) + 1,
      2 -> result(1) := position(1) + 1,
      others -> result(2) := position(2) - 1
     end
    ),
    1 -> (
     cases index:
      1 -> result(1) := position(1) + 1,
      2 -> result(2) := position(2) - 1,
      others -> result(1) := position(1) - 1
     end
    ),
    2 -> (
     cases index:
      1 -> result(2) := position(2) - 1,
      2 -> result(1) := position(1) - 1,
      others -> result(2) := position(2) + 1
     end
    ),
    3 -> (
     cases index:
      1 -> result(1) := position(1) - 1,
      2 -> result(2) := position(2) + 1,
      others -> result(1) := position(1) + 1
     end
    )
   end;
   return result
  )
  pre index in set {1, ..., 4}
   and Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
  post Tetramino`checkPosition(RESULT, 0, Board`maxRow + 1, 0, Board`maxColumn + 1);

  protected getRotatedMino: Board`Position ==> Board`Position
  getRotatedMino(position) == (
   dcl result : Board`Position := position;
   cases Tetramino`getOrientation():

    0 -> result(2) := position(2) + 1,
    1 -> result(1) := position(1) + 1,
    2 -> result(2) := position(2) - 1,
    3 -> result(1) := position(1) - 1
   end;
   return result
  )
  pre Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
  post Tetramino`checkPosition(RESULT, -1, Board`maxRow + 2, -1, Board`maxColumn + 2);

end TetraminoO
```

3.8 TetraminoS

```
class TetraminoS is subclass of Tetramino
```

```
-- Tetramino of the type J:  xx
--         xx
--
-- Minoes:       21
--         43


operations

 public TetraminoS : (Game) ==> TetraminoS
 TetraminoS(game) == (
  Tetramino`setColor(<Green>);

  Tetramino`setId(5);
  Tetramino`initialSetMinoes(game, [1, 6]);
  return self
 );

 protected getNextMino: Board`Position * nat ==> Board`Position
 getNextMino(position, index) == (
  dcl result : Board`Position := position;

  cases Tetramino`getOrientation():
   0 -> (
    cases index:
     2 -> result(1) := position(1) + 1,
     others -> result(2) := position(2) - 1
    end
   ),
   1 -> (
    cases index:
     2 -> result(2) := position(2) - 1,
     others -> result(1) := position(1) - 1
    end
   ),
   2 -> (
    cases index:
     2 -> result(1) := position(1) - 1,
     others -> result(2) := position(2) + 1
    end
   ),
   3 -> (
    cases index:
     2 -> result(2) := position(2) + 1,
     others -> result(1) := position(1) + 1
    end
   )
  end;
  return result
 )
 pre index in set {1, ..., 4}
  and Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
 post Tetramino`checkPosition(RESULT, 0, Board`maxRow + 1, 0, Board`maxColumn + 1);

 protected getRotatedMino: Board`Position ==> Board`Position
 getRotatedMino(position) == (
  dcl result : Board`Position := position;
  cases Tetramino`getOrientation():

   0 -> result(1) := position(1) + 2,
   1 -> result(2) := position(2) - 2,
   2 -> result(1) := position(1) - 2,
   3 -> result(2) := position(2) + 2
  end;
```

```
   return result
  )
  pre Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
  post Tetramino`checkPosition(RESULT, -1, Board`maxRow + 2, -1, Board`maxColumn + 2);

end TetraminoS
```

3.9 TetraminoT

```
class TetraminoT is subclass of Tetramino

 -- Tetramino of the type J:  x
 --       xxx
 --
 -- Minoes:        1
 --         234


 operations

  public TetraminoT : (Game) ==> TetraminoT
  TetraminoT(game) == (
   Tetramino`setColor(<Purple>);

   Tetramino`setId(6);
   Tetramino`initialSetMinoes(game, [1, 5]);
   return self
  );

  protected getNextMino: Board`Position * nat ==> Board`Position
  getNextMino(position, index) == (
   dcl result : Board`Position := position;

   cases Tetramino`getOrientation():
    0 -> (
     cases index:
      1 -> (
       result(1) := position(1) + 1;
       result(2) := position(2) - 1;
      ),
      others -> result(2) := position(2) + 1
     end
    ),
    1 -> (
     cases index:
      1 -> (
       result(1) := position(1) - 1;
       result(2) := position(2) - 1;
      ),
      others -> result(1) := position(1) + 1
     end
    ),
    2 -> (
     cases index:
      1 -> (
       result(1) := position(1) - 1;
       result(2) := position(2) + 1;
      ),
      others -> result(2) := position(2) - 1
     end
    ),
```

```
    3 -> (
     cases index:
      1 -> (
       result(1) := position(1) + 1;
       result(2) := position(2) + 1;
      ),
      others -> result(1) := position(1) - 1
     end
    )
   end;
   return result
  )
  pre index in set {1, ..., 4}
   and Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
  post Tetramino`checkPosition(RESULT, 0, Board`maxRow + 1, 0, Board`maxColumn + 1);

  protected getRotatedMino: Board`Position ==> Board`Position
  getRotatedMino(position) == (
   dcl result : Board`Position := position;

   cases Tetramino`getOrientation():
    0 -> (
     result(1) := position(1) + 1;
     result(2) := position(2) + 1;
     ),
    1 -> (
     result(1) := position(1) + 1;
     result(2) := position(2) - 1;
     ),
    2 -> (
     result(1) := position(1) - 1;
     result(2) := position(2) - 1;
     ),
    3 -> (
     result(1) := position(1) - 1;
     result(2) := position(2) + 1;
     )
   end;
   return result
  )
  pre Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
  post Tetramino`checkPosition(RESULT, -1, Board`maxRow + 2, -1, Board`maxColumn + 2);

end TetraminoT
```

3.10 TetraminoZ

```
class TetraminoZ is subclass of Tetramino

 -- Tetramino of the type Z: xx
 --         xx
 --
 -- Minoes:      12
 --             34


 operations

  public TetraminoZ : (Game) ==> TetraminoZ
  TetraminoZ(game) == (
   Tetramino`setColor(<Red>);
```

```
   Tetramino`setId(7);
   Tetramino`initialSetMinoes(game, [1, 4]);
   return self
  );

  protected getNextMino: Board`Position * nat ==> Board`Position
  getNextMino(position, index) == (
   dcl result : Board`Position := position;

   cases Tetramino`getOrientation():
    0 -> (
     cases index:
      2 -> result(1) := position(1) + 1,
      others -> result(2) := position(2) + 1
     end
    ),
    1 -> (
     cases index:
      2 -> result(2) := position(2) - 1,
      others -> result(1) := position(1) + 1
     end
    ),
    2 -> (
     cases index:
      2 -> result(1) := position(1) - 1,
      others -> result(2) := position(2) - 1
     end
    ),
    3 -> (
     cases index:
      2 -> result(2) := position(2) + 1,
      others -> result(1) := position(1) - 1
     end
    )
   end;
   return result
  )
  pre index in set {1, ..., 4}
   and Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
  post Tetramino`checkPosition(RESULT, 0, Board`maxRow + 1, 0, Board`maxColumn + 1);

  protected getRotatedMino: Board`Position ==> Board`Position
  getRotatedMino(position) == (
   dcl result : Board`Position := position;
   cases Tetramino`getOrientation():

    0 -> result(2) := position(2) + 2,
    1 -> result(1) := position(1) + 2,
    2 -> result(2) := position(2) - 2,
    3 -> result(1) := position(1) - 2
   end;
   return result
  )
  pre Tetramino`checkPosition(position, 1, Board`maxRow, 1, Board`maxColumn)
  post Tetramino`checkPosition(RESULT, -1, Board`maxRow + 2, -1, Board`maxColumn + 2);

end TetraminoZ
```

4 Model Validation

4.1 TestCaseExtra

```
class TestCaseExtra

 -- Class obtained from the Vending Machine example of MFES


 operations
 -- Simulates assertion checking by reducing it to pre-condition checking.
 -- If 'arg' does not hold, a pre-condition violation will be signaled.
 protected assertTrue: bool ==> ()

 assertTrue(arg) ==
  return
 pre arg;

 -- Simulates assertion checking by reducing it to post-condition checking.
 -- If values are not equal, prints a message in the console and generates
 -- a post-conditions violation.
 protected assertEqual: ? * ? ==> ()

 assertEqual(expected, actual) ==
  if expected <> actual then (
     IO`print("Actual value (");
     IO`print(actual);
     IO`print(") different from expected (");
     IO`print(expected);
     IO`println(")\n")
  )
 post expected = actual

end TestCaseExtra
```

4.2 TestTetris

```
class TestTetris is subclass of TestCaseExtra

 instance variables

  private printBoard : Game`String := "";


 operations


  -- Prints the initial board matrix and checks it is as should be for tests.
  private initalMatrix_test: Game * bool * bool * bool ==> ()
  initalMatrix_test(game, printNow, blackConsole, testPrint) == (
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertEqual(printBoard,
    "\n|          |" ^
    "\n|          |" ^

    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
```

```
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n ----------")
);

-- Adds a tetramino of type I to the board and checks it is in the right position.
private addTetramino1_test: Game * bool * bool * bool ==> ()
addTetramino1_test(game, printNow, blackConsole, testPrint) == (
 game.newTetramino(1);
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(printBoard,
  "\n|          |" ^
  "\n|   ****   |" ^

  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
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  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n ----------")
);

-- Adds a tetramino of type J to the board and checks it is in the right position.
private addTetramino2_test: Game * bool * bool * bool ==> ()
addTetramino2_test(game, printNow, blackConsole, testPrint) == (
 game.newTetramino(2);
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(printBoard,

  "\n|   *      |" ^
  "\n|   ***    |" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
  "\n|##########|" ^
```

```
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|###****###|" ^
    "\n ----------")
  );

  -- Adds a tetramino of type L to the board and checks it is in the right position.
  private addTetramino3_test: Game * bool * bool * bool ==> ()
  addTetramino3_test(game, printNow, blackConsole, testPrint) == (
   game.newTetramino(3);

   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertEqual(printBoard,
    "\n|     *    |" ^
    "\n|   ***    |" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
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    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|*#########|" ^
    "\n|*******###|" ^
    "\n ----------")
  );

  -- Adds a tetramino of type O to the board and checks it is in the right position.
  private addTetramino4_test: Game * bool * bool * bool ==> ()

  addTetramino4_test(game, printNow, blackConsole, testPrint) == (
   game.newTetramino(4);
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertEqual(printBoard,
    "\n|    **    |" ^
    "\n|    **    |" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
```

```
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|*########*|" ^
    "\n ----------")
  );


  -- Adds a tetramino of type S to the board and checks it is in the right position.
  private addTetramino5_test: Game * bool * bool * bool ==> ()
  addTetramino5_test(game, printNow, blackConsole, testPrint) == (
   game.newTetramino(5);
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertEqual(printBoard,
    "\n|    **    |" ^
    "\n|   **     |" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|####**####|" ^
    "\n|*###**###*|" ^
    "\n ----------")

  );

  -- Adds a tetramino of type T to the board and checks it is in the right position.
  private addTetramino6_test: Game * bool * bool * bool ==> ()
  addTetramino6_test(game, printNow, blackConsole, testPrint) == (
   game.newTetramino(6);
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertEqual(printBoard,
    "\n|    *     |" ^
    "\n|   ***    |" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
```

```
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|####**##**|" ^

    "\n|*###**#***|" ^
    "\n ----------")
  );

  -- Adds a tetramino of type Z to the board and checks it is in the right position.
  private addTetramino7_test: Game * bool * bool * bool ==> ()
  addTetramino7_test(game, printNow, blackConsole, testPrint) == (
   game.newTetramino(7);
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertEqual(printBoard,
    "\n|   **     |" ^
    "\n|    **    |" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
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    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^

    "\n|######*###|" ^
    "\n|###******|" ^
    "\n|*###******|" ^
    "\n ----------")
  );

  -- Adds another tetramino of type S to the board and checks it is in the right position.
  private addTetramino8_test: Game * bool * bool * bool ==> ()
  addTetramino8_test(game, printNow, blackConsole, testPrint) == (
   game.newTetramino(5);
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertEqual(printBoard,
    "\n|    **    |" ^
    "\n|   **     |" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
```

```
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^
    "\n|##########|" ^

    "\n|######*###|" ^
    "\n|**##******|" ^
    "\n|***#******|" ^
    "\n ----------")
  );

  -- Moves the first tetramino several times and in several ways and checks the drop
  -- amount as well as the score and the lines.
  private moveTetramino1_test: Game * bool * bool * bool ==> ()
  moveTetramino1_test(game, printNow, blackConsole, testPrint) == (
   assertTrue(game.down());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertTrue(game.down());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertTrue(game.rotate());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertTrue(game.rotate());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertTrue(game.rotate());

   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertTrue(game.rotate());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertEqual(game.drop(), 18);
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertEqual(game.getScore(), 18);
   assertEqual(game.checkLines(), 0);
  );

  -- Moves the second tetramino several times and in several ways and checks the drop
  -- amount as well as the score and the lines.
  private moveTetramino2_test: Game * bool * bool * bool ==> ()
  moveTetramino2_test(game, printNow, blackConsole, testPrint) == (
   assertTrue(game.down());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertTrue(game.down());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertTrue(game.rotate());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertTrue(game.rotate());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertTrue(game.rotate());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertTrue(game.rotate());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);

   assertTrue(game.left());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertTrue(game.left());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertTrue(game.left());
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertEqual(game.drop(), 18);
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
   assertEqual(game.getScore(), 36);
```

```
 assertEqual(game.checkLines(), 0);
);

-- Moves the third tetramino several times and in several ways and checks the drop
-- amount as well as the score and the lines.
private moveTetramino3_test: Game * bool * bool * bool ==> ()
moveTetramino3_test(game, printNow, blackConsole, testPrint) == (
 assertTrue(game.down());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.down());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.right());

 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.right());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.right());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.right());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(game.drop(), 18);
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(game.getScore(), 54);
 assertEqual(game.checkLines(), 1);
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(game.getScore(), 154);
);

-- Moves the fourth tetramino several times and in several ways and checks the drop
-- amount as well as the score and the lines.
private moveTetramino4_test: Game * bool * bool * bool ==> ()
moveTetramino4_test(game, printNow, blackConsole, testPrint) == (

 assertTrue(game.down());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.down());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(game.drop(), 18);
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(game.getScore(), 172);
 assertEqual(game.checkLines(), 0);
);

-- Moves the fifth tetramino several times and in several ways and checks the drop
-- amount as well as the score and the lines.
private moveTetramino5_test: Game * bool * bool * bool ==> ()
moveTetramino5_test(game, printNow, blackConsole, testPrint) == (
 assertTrue(game.down());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
```

```
 assertTrue(game.down());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());

 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.right());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.right());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.right());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.right());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(game.drop(), 18);
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(game.getScore(), 190);
 assertEqual(game.checkLines(), 0);
);

-- Moves the sixed tetramino several times and in several ways and checks the drop
-- amount as well as the score and the lines.
private moveTetramino6_test: Game * bool * bool * bool ==> ()
moveTetramino6_test(game, printNow, blackConsole, testPrint) == (

 assertTrue(game.down());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.down());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.right());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.right());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(game.drop(), 17);
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(game.getScore(), 207);
 assertEqual(game.checkLines(), 0);
);

-- Moves the seventh tetramino several times and in several ways and checks the drop

-- amount as well as the score and the lines.
private moveTetramino7_test: Game * bool * bool * bool ==> ()
moveTetramino7_test(game, printNow, blackConsole, testPrint) == (
 assertTrue(game.down());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.down());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
```

```
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.left());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.left());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.left());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);

 assertEqual(game.drop(), 18);
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(game.getScore(), 225);
 assertEqual(game.checkLines(), 0);
);

-- Moves the eighted tetramino several times and in several ways and checks the drop
-- amount as well as the score and the lines.
private moveTetramino8_test: Game * bool * bool * bool ==> ()
moveTetramino8_test(game, printNow, blackConsole, testPrint) == (
 assertTrue(game.down());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.down());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.rotate());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.left());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertTrue(game.left());
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(game.drop(), 17);
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(game.getScore(), 242);
 assertEqual(game.checkLines(), 2);
 printBoard := game.printBoard(printNow, blackConsole, testPrint);
 assertEqual(game.getScore(), 542);
);

-- Plays the game for a while, using only I tetraminoes, to test the number of lines
-- completed, as well as the score and level increments.
private play_test: Game * bool * bool * bool ==> ()
play_test(game, printNow, blackConsole, testPrint) == (
 dcl column: nat := 0;
 for i = 1 to 40 do (
  game.newTetramino(1);
  assertTrue(game.down());
  printBoard := game.printBoard(printNow, blackConsole, testPrint);
  assertTrue(game.down());

  printBoard := game.printBoard(printNow, blackConsole, testPrint);
  assertTrue(game.rotate());
  printBoard := game.printBoard(printNow, blackConsole, testPrint);
  while game.left() do
   printBoard := game.printBoard(printNow, blackConsole, testPrint);
  for j = 1 to column do
   if game.right() then
    printBoard := game.printBoard(printNow, blackConsole, testPrint);
  if column = 2 or column = 6 then assertEqual(game.drop(), 15)
  else assertEqual(game.drop(), 16);
  printBoard := game.printBoard(printNow, blackConsole, testPrint);
  if column = 9 then (
   assertEqual(game.checkLines(), 4);
```

```
     printBoard := game.printBoard(true, true, true)
    )

    else assertEqual(game.checkLines(), 0);
    column := (column + 1) mod 10;
    if i = 20 then (
     assertEqual(game.getLines(), 11);
     assertEqual(game.getLevel(), 2);
     assertEqual(game.getScore(), 542 + 16 * 16 + 15 * 4 + 800 * 2);
    )
   );
   assertEqual(game.getLines(), 19);
   assertEqual(game.getLevel(), 2);
   assertEqual(game.getScore(), 2458 + 16 * 16 * 2 + 15 * 4 * 2 + 800 * 2 * 2);
  );

  -- Randomly generates tetraminoes and drops them, in order to test that the game
  -- ends correctly.
  private gameOver_test: Game * bool * bool * bool ==> ()
  gameOver_test(game, printNow, blackConsole, testPrint) == (

   while not game.getGameOver() do (
    game.newRandomTetramino();
    printBoard := game.printBoard(printNow, blackConsole, testPrint);
    if game.drop() > 0
    then printBoard := game.printBoard(printNow, blackConsole, testPrint);
    if game.checkLines() > 0
    then printBoard := game.printBoard(printNow, blackConsole, testPrint);
   );
   assertTrue(game.getGameOver());
  );

  -- Runs all the tests, printing the board for further visual
  -- confirmation of the results.
  public static main: bool * bool * bool ==> ()
  main(printNow, blackConsole, testPrint) == (
   dcl game: Game := new Game();
   IO`print("\n##### TESTS #####\n");
   new TestTetris().initalMatrix_test(game, printNow, blackConsole, testPrint);
   new TestTetris().addTetramino1_test(game, printNow, blackConsole, testPrint);
   new TestTetris().moveTetramino1_test(game, printNow, blackConsole, testPrint);
   new TestTetris().addTetramino2_test(game, printNow, blackConsole, testPrint);
   new TestTetris().moveTetramino2_test(game, printNow, blackConsole, testPrint);
   new TestTetris().addTetramino3_test(game, printNow, blackConsole, testPrint);
   new TestTetris().moveTetramino3_test(game, printNow, blackConsole, testPrint);
   new TestTetris().addTetramino4_test(game, printNow, blackConsole, testPrint);
   new TestTetris().moveTetramino4_test(game, printNow, blackConsole, testPrint);
   new TestTetris().addTetramino5_test(game, printNow, blackConsole, testPrint);
   new TestTetris().moveTetramino5_test(game, printNow, blackConsole, testPrint);
   new TestTetris().addTetramino6_test(game, printNow, blackConsole, testPrint);
   new TestTetris().moveTetramino6_test(game, printNow, blackConsole, testPrint);
   new TestTetris().addTetramino7_test(game, printNow, blackConsole, testPrint);
   new TestTetris().moveTetramino7_test(game, printNow, blackConsole, testPrint);
   new TestTetris().addTetramino8_test(game, printNow, blackConsole, testPrint);
   new TestTetris().moveTetramino8_test(game, printNow, blackConsole, testPrint);
   new TestTetris().play_test(game, printNow, blackConsole, testPrint);
   new TestTetris().gameOver_test(game, printNow, blackConsole, testPrint);
  );

end TestTetris
```

4.3 Game Coverage

Function or operation	Line	Coverage	Calls
Game	35	100.0%	1
checkLines	104	100.0%	62
down	72	100.0%	96
drop	94	100.0%	62
getBoard	39	100.0%	309
getGameOver	47	100.0%	78
getLevel	119	100.0%	2
getLines	116	100.0%	2
getScore	113	100.0%	12
left	77	100.0%	248
newRandomTetramino	67	100.0%	14
newTetramino	52	100.0%	62
printBoard	128	100.0%	654
right	82	100.0%	190
rotate	87	100.0%	70
setGameOver	43	100.0%	4
Game.vdmpp		100.0%	1866

4.4 Board Coverage

Function or operation	Line	Coverage	Calls
Board	39	100.0%	1
checkRow	105	100.0%	1364
checkRows	118	100.0%	62
getBoardPrint	59	100.0%	654
getCellPrint	82	21.3%	143880
getMatrixPosition	132	100.0%	6349
initBoard	46	100.0%	1
setMatrixPosition	127	100.0%	12924
Board.vdmpp		74.8%	165235

Note: The coverage for getCellPrint is not 100.0% because part of that function is used for printing in color and that is not the print mode for tests.

4.5 Tetramino Coverage

Function or operation	Line	Coverage	Calls
addTetramino	147	100.0%	1646
checkMinoes	49	100.0%	8172
checkPosition	39	100.0%	145640
drop	185	100.0%	62
getNextMino	122	100.0%	2
getOrientation	65	100.0%	6392
getRotatedMino	128	100.0%	2
initialSetMinoes	98	100.0%	62
moveDown	154	100.0%	1077

moveLeft	161	100.0%	248
moveRight	168	100.0%	190
removeTetramino	140	100.0%	1585
rotate	175	100.0%	70
setColor	58	100.0%	62
setId	61	100.0%	62
setMinoes	73	100.0%	1585
validPosition	134	100.0%	6428
Tetramino.vdmpp		100.0%	173285

4.6 TetraminoI Coverage

Function or operation	Line	Coverage	Calls
TetraminoI	12	100.0%	43
getNextMino	20	100.0%	4971
getRotatedMino	34	100.0%	44
TetraminoI.vdmpp		100.0%	5058

4.7 TetraminoJ Coverage

Function or operation	Line	Coverage	Calls
TetraminoJ	12	100.0%	4
getNextMino	20	100.0%	258
getRotatedMino	55	100.0%	4
TetraminoJ.vdmpp		100.0%	266

4.8 TetraminoL Coverage

Function or operation	Line	Coverage	Calls
TetraminoL	12	100.0%	2
getNextMino	20	100.0%	146
getRotatedMino	55	100.0%	4
TetraminoL.vdmpp		100.0%	152

4.9 TetraminoO Coverage

Function or operation	Line	Coverage	Calls
TetraminoO	11	100.0%	3
getNextMino	19	100.0%	250
getRotatedMino	58	100.0%	4
TetraminoO.vdmpp		100.0%	257

4.10 TetraminoS Coverage

Function or operation	Line	Coverage	Calls

TetraminoS	12	100.0%	6
getNextMino	20	100.0%	416
getRotatedMino	55	100.0%	5
TetraminoS.vdmpp		100.0%	427

4.11 TetraminoT Coverage

Function or operation	Line	Coverage	Calls
TetraminoT	12	100.0%	2
getNextMino	20	100.0%	157
getRotatedMino	67	100.0%	5
TetraminoT.vdmpp		100.0%	164

4.12 TetraminoZ Coverage

Function or operation	Line	Coverage	Calls
TetraminoZ	12	100.0%	2
getNextMino	20	100.0%	124
getRotatedMino	55	100.0%	4
TetraminoZ.vdmpp		100.0%	130

5 Model Verification

5.1 Example of Domain Verification

One of the proof obligations generated by Overture is:

No.	PO Name	Type
7	Board‘checkRow	legal map application

The code under analysis, with the relevant map application, are in line 7:

```
if blackConsole then
        cases id:
                0 -> if row < 3 then return "␣" else return[Ư'+FF
                others -> return[Ư'+FFF'D]
        end
else
        cases id:
                0 -> if row < 3 then return "␣" else return[Ư'+FF
                1 -> return "\u001B[38;5;51m" ^[Ư'+FFF'D]^ "\u001B[
```

The proof obligation of Overture also generated a view with the result

forall row:int & ([i, j] in set (dom matrix))

where we can see that each values of i and j are in the domain of the matrix, and only with that values we can access the matrix.

5.2 Example of Invariant Verification

Another proof obligation generated by Overture is:

No.	PO Name	Type
1	Board‘Position	type invariant satisfiable

The code under analysis, with the relevant map application, are in line 1:

```
types
```

...

exists position:Position & ((len position) = 2)

6 Code Generation

We used Overture to generate java code for our model. After that, we made a simple java Main module that allows for basic game playing or test running. Although with some limitations, due to the use of the console, that game can be played well.

6.1 Java Main Class

```
1  import tetris.vdm.*;
   import java.util.Scanner;

   public class Main {
5
       private static boolean moveDown = true;
       private static String input = "";
       private static Scanner scanner = new Scanner(System.in);
       private static boolean gameState = false;
10
       public static void main(String[] args) {

           System.out.println("\n\u001B[37m\u001B[1m Welcome to Tetris\u001B[0
               m\n");
           System.out.println("\u001B[37m\u001B[1m > a: Play game\u001B[0m");
15         System.out.println("\u001B[37m\u001B[1m > b: Run VDM tests\u001B[0m
               ");
           input = scanner.nextLine();

           System.out.print("\033[H\033[2J");
           System.out.flush();
20
           if (input.equals("a")) {
               Game game = new Game();
               game.newRandomTetramino();
               System.out.println(game.printBoard(false, true, false));
25
               while (!gameState) {
                   try {
                       gameState = game.getGameOver();
                       moveDown = game.down();
30
                       System.out.println(game.printBoard(false, false, false)
                           );
```

```
                    System.out.println("\u001B[37m\u001B[1m Level " + game.
                        getLevel() + "\u001B[0m");
                    System.out.println("\u001B[37m\u001B[1m Lines " + game.
                        getLines() + "\u001B[0m");
                    System.out.println("\u001B[37m\u001B[1m Score " + game.
                        getScore() + "\u001B[0m" + "\n");

                    System.out.println("\u001B[37m\u001B[1m"
                            + " Use the keys a(left), d(right), s(rotate),
                                f(drop) q(exit) to move the pieces: "
                            + "\u001B[0m");
                    input = scanner.nextLine();

                    if (input.equals("a"))
                        game.left();
                    else if (input.equals("d"))
                        game.right();
                    else if (input.equals("s"))
                        game.rotate();
                    else if (input.equals("f"))
                        game.drop();
                    else if (input.equals("q"))
                        gameState = true;
                    else if (!moveDown) {
                        game.checkLines();
                        game.newRandomTetramino();
                    } else
                        moveDown = game.down();

                    System.out.print("\033[H\033[2J");
                    System.out.flush();

                } catch (Exception e) {
                    e.printStackTrace();
                }
            }

            System.out.println("\u001B[37m\u001B[1m Game Over!\u001B[0m");
            System.out.println("\u001B[37m\u001B[1m Level " + game.getLevel
                () + "\u001B[0m");
            System.out.println("\u001B[37m\u001B[1m Score " + game.getScore
                () + "\u001B[0m" + "\n");
            System.out.println("\u001B[37m\u001B[1m Press any key to close
                the game\u001B[0m");
            input = scanner.nextLine();
        }

        else
            TestTetris.main(true, true, true);

    }

}
```

7 Conclusions

The model that was developed by us covers all the requirements included implicitly on the theme project and the list of requirements descripted in section 1.2. In the final and after model verifications, we all see the game developed in VDM++ like one of the projects more consistent and safer that we have ever developed during the course. In addition it is noticed that all the elements of the group have already had contact in the past with the game and continue feeling enthuse with this version developed by us. Maybe in the future we can all add more features to this game and make it appears near the original version. This project took approximately 16 hours to

develop. example in the vending machine

8 References

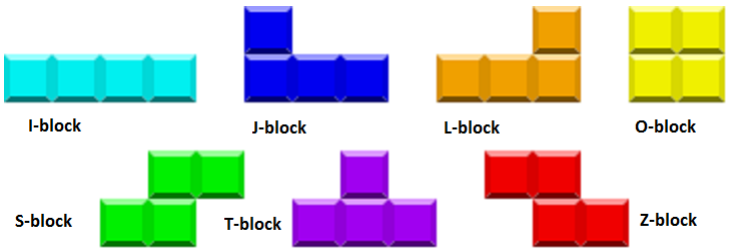
1. https://en.wikipedia.org/wiki/Tetris
2. http://tetris.com/
3. https://tetris.wiki/Tetris_Guideline
4. http://overturetool.org/
5. http://tetris.com/play-tetris/

A Indispensable formal rules

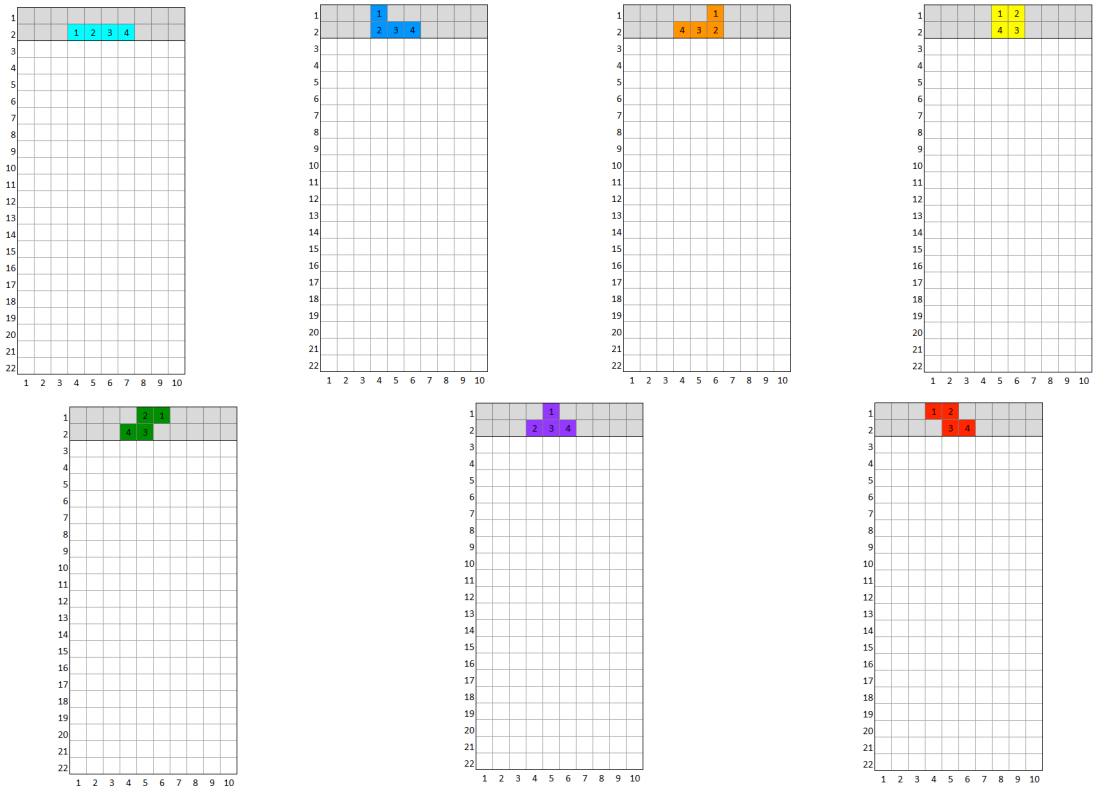
In this section we present the formal rules that Tetris game must follow. We already present other rules, named informal and in a player view way in section 1.1.

- Playfield is 10 cells wide and at least 22 cells tall, where rows above 20 are hidden or obstructed by the field frame. We follow in our case 10 cells wide and 22 cells tall where the player can see the first 20 rows and the 2 last cells are invisible to the player.
- The tetramino colors are:
  Cyan I;
  Yellow O;
  Purple T;
  Green S;
  Red Z;
  Blue J;
  Orange L.
- Each tetramino appear on these exactly locations:
  The I and O spawn in the middle columns;
  The rest spawn in the left-middle columns;
  The tetraminoes spawn horizontally and with their flat side pointed down.
- Super Rotation System (SRS) specifies tetramino rotation.
- Standard mappings for console and handheld gamepads: Up, Down, Left, Right on joystick perform locking hard drop, non-locking soft drop (except first frame locking in some games), left shift, and right shift respectively. Left fire button rotates 90 degrees counterclockwise, and right fire button rotates 90 degrees clockwise.
- So-called Random Generator (also called “random bag” or “7 system”)
- Player may only level up by clearing lines. Required lines depends in the game.
- The player tops out when a piece is spawned overlapping at least one block, or a piece locks completely above the visible portion of the playfield.

B The 7 tetraminoes

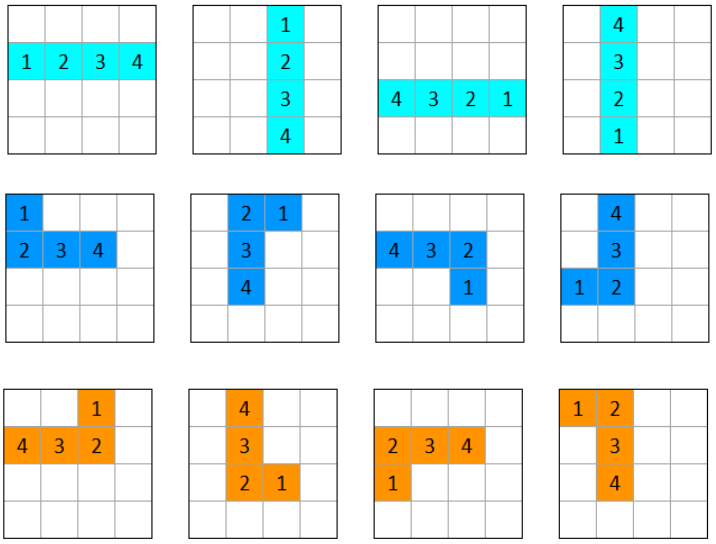


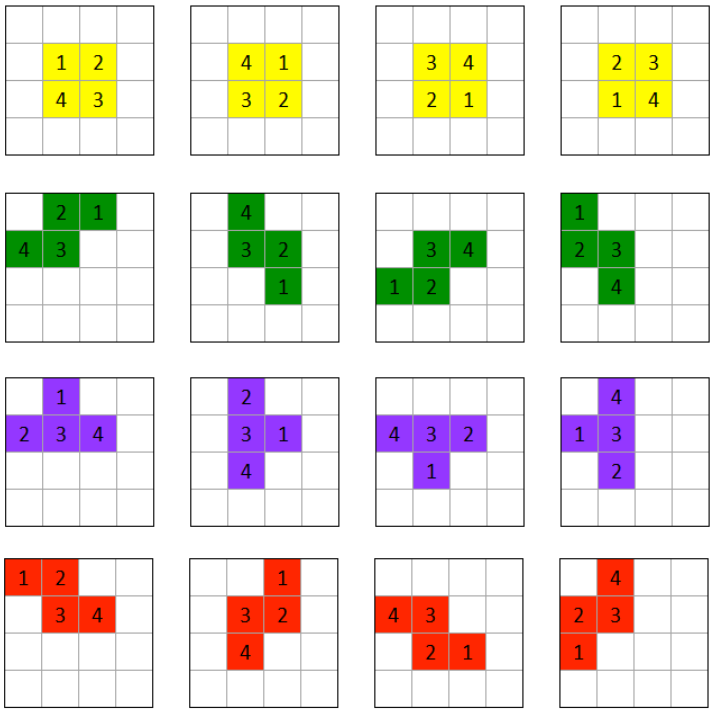
C Spawn Position for Each Tetramino



Note: The numbers 1, 2, 3 and 4 inside the tetraminoes indicate each mino.

D All Possible Orientations of Each Tetramino




1 2
4 3
4 1
3 2
3 4
2 1
2 3
1 4
2 1
4 3
4
3 2
1
3 4
1 2
1
2 3
4
1
2 3 4
2 3 1
4
4 3 2
1
4
1 3
2
1 2
3 4
1
3 2
4
4 3
2 1
4
2 3
1