CHESSVDM

OVT-21 workshop

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March 10, 2023

OUTLINE

1. Introduction
2. Paper summary
3. Invariants on Compound Types in VDM++
4. Other topics

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BACKGROUND (MORTEN)

- C++ guy
  - Low-level details
  - References vs. values
  - Object lifetimes
- Love discussing software paradigms
- MSc. Computer Engineering
- Looking into PhD related to static analysis and tooling

MOTIVATION

- Different perspective
  - Providing an **educational example** and comparing **modelling styles**
  - Not a critical system
  - Not focusing on “proving Chess”
- Exploring capabilities of VDM++
  - Interesting bugs with VDM++
- Everyone knows Chess
  - Understandable
  - Complex

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2. **Paper summary**
3. Invariants on Compound Types in VDM++
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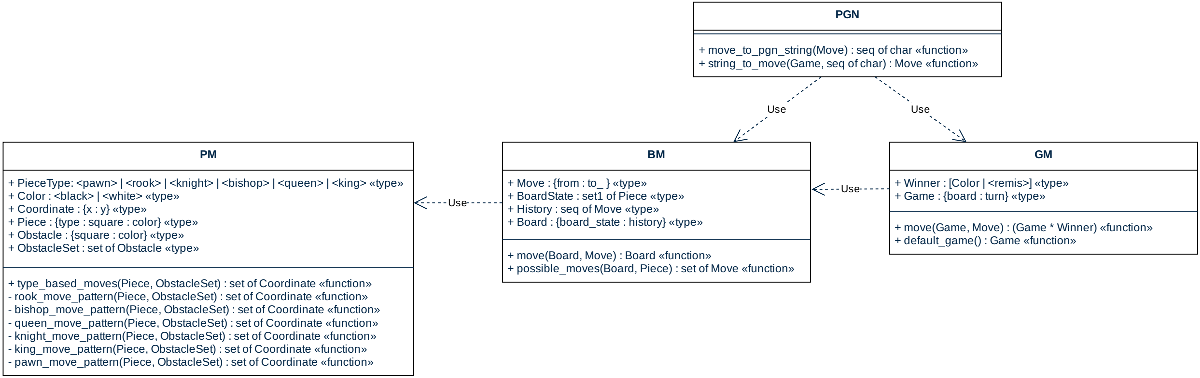
PAPER SUMMARY

- Chess modelled in VDM++
- Explored different paradigms
- Initially OOP but then FP
  - VDM-SL like
  - Composite types - immutable data
  - Why?

MODEL STRUCTURE



PGN

+ move_to_pgn_string(Move) : seq of char «function»
+ string_to_move(Game, seq of char) : Move «function»

PM

+ PieceType: <pawn> | <rook> | <knight> | <bishop> | <queen> | <king> «type»
+ Color : <black> | <white> «type»
+ Coordinate : {x : y} «type»
+ Piece : {type : square : color} «type»
+ Obstacle : {square : color} «type»
+ ObstacleSet : set of Obstacle «type»

+ type_based_moves(Piece, ObstacleSet) : set of Coordinate «function»
- rook_move_pattern(Piece, ObstacleSet) : set of Coordinate «function»
- bishop_move_pattern(Piece, ObstacleSet) : set of Coordinate «function»
- queen_move_pattern(Piece, ObstacleSet) : set of Coordinate «function»
- knight_move_pattern(Piece, ObstacleSet) : set of Coordinate «function»
- king_move_pattern(Piece, ObstacleSet) : set of Coordinate «function»
- pawn_move_pattern(Piece, ObstacleSet) : set of Coordinate «function»

BM

+ Move : {from : to_ } «type»
+ BoardState : set1 of Piece «type»
+ History : seq of Move «type»
+ Board : {board_state : history} «type»

+ move(Board, Move) : Board «function»
+ possible_moves(Board, Piece) : set of Move «function»

GM

+ Winner : [Color | <remis>] «type»
+ Game : {board : turn} «type»

+ move(Game, Move) : (Game * Winner) «function»
+ default_game() : Game «function»

Figure 1: Overview of the model structure.

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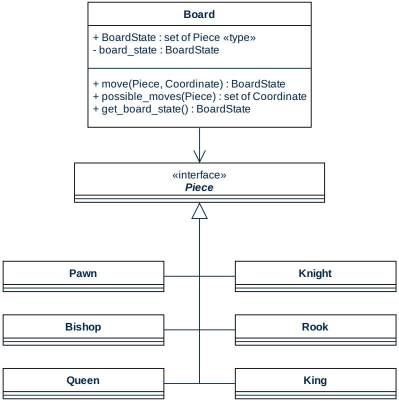
CONTEXT

- Writing a Chess model with OO structure
- Implementing `move` operation
- Odd behaviour occurred during tests



Board
+ BoardState : set of Piece «type»
- board_state : BoardState
+ move(Piece, Coordinate) : BoardState
+ possible_moves(Piece) : set of Coordinate
+ get_board_state() : BoardState
«interface»
Piece
Pawn
Knight
Bishop
Rook
Queen
King

Figure 2: Initial OOP structure. Operations of `Piece` and subclasses left out.

ORIGINAL MODEL

```
class Board
types
    public BoardState = set1 of Piece
    inv s == forall p1, p2 in set s & p1 <> p2 => p1.position <> p2.position;

instance variables
    public board_state : BoardState;

operations
    public move: Piece * Piece`Coordinate ==> ()
    move(piece, coord) == (
        let dead_piece = {p | p in set board_state & p.position = coord} in
            board_state := board_state \ dead_piece;
        piece.position := coord
    )
    pre piece in set board_state and coord in set piece.possible_moves(board_state);
```

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class Board
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    public BoardState = set1 of Piece
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            board_state := board_state \ dead_piece;
        piece.position := coord
    )
    pre piece in set board_state and coord in set piece.possible_moves(board_state);
```

Seems fine, right?

EXECUTING MODEL

```
class Board
types
    public BoardState = set1 of Piece
    inv s == forall p1, p2 in set s & p1 <> p2 => p1.position <> p2.position;

instance variables
    public board_state : BoardState;

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    public move: Piece * Piece`Coordinate ==> ()
    move(piece, coord) == (
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            board_state := board_state \ dead_piece;
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    pre piece in set board_state and coord in set piece.possible_moves(board_state);
```

OLD BEHAVIOUR

Debugging `move`:

1. `dead_piece` removed from `board_state`
2. Invariant for `board_state` checked
3. `piece` position updated
4. Invariant for `board_state` checked
   - Since `piece` refers to an object inside `board_state`
5. `BoardState` **invariant violated**

Invariant was checked on `board_state` with `dead_piece` in it

GITHUB ISSUE

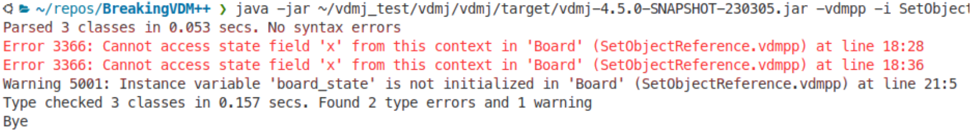
The actions:

- Posted issue on GitHub
- More complex than anticipated
- Lead to discussion related to VDMJ internals
- Fixed within 14 days by Nick Battle
- *But then...*

Link to discussion:

`https://github.com/overturetool/vdm-vscode/issues/197`

NEW BEHAVIOUR



```
~/repos/BreakingVDM++ ❯ java -jar ~/vdmj_test/vdmj/vdmj/target/vdmj-4.5.0-SNAPSHOT-230305.jar -vdmpp -i SetObjec
Parsed 3 classes in 0.053 secs. No syntax errors
Error 3366: Cannot access state field 'x' from this context in 'Board' (SetObjectReference.vdmpp) at line 18:28
Error 3366: Cannot access state field 'x' from this context in 'Board' (SetObjectReference.vdmpp) at line 18:36
Warning 5001: Instance variable 'board_state' is not initialized in 'Board' (SetObjectReference.vdmpp) at line 21:5
Type checked 3 classes in 0.157 secs. Found 2 type errors and 1 warning
Bye
```

Figure 3: New behaviour after fixing the issue.

Direct field access from functions (such as `inv_BoardState`) now prohibited

THE UNDERLYING ISSUE

VDM++ objects are references:

- Reference types vs. value types
- Mutable vs. immutable
- Aliasing

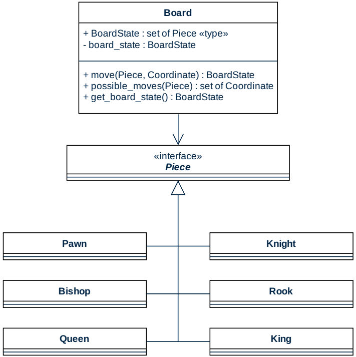
Some options with invariants[1] on compound types of references:

1. Check invariant whenever an object that is referred to changes state
2. **Prohibit such invariants**

[1] Similar points with to pre- and postconditions

How can we express the invariant?

STRUCTURE COMPARISON



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- board_state : BoardState

+ move(Piece, Coordinate) : BoardState
+ possible_moves(Piece) : set of Coordinate
+ get_board_state() : BoardState

«interface»
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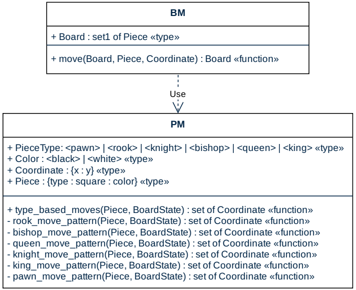
Figure 4: Previous structure of the model.



BM

+ Board : set1 of Piece «type»

+ move(Board, Piece, Coordinate) : Board «function»

Use

PM

+ PieceType: <pawn> | <rook> | <knight> | <bishop> | <queen> | <king> «type»
+ Color : <black> | <white> «type»
+ Coordinate : {x : y} «type»
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Figure 5: New structure of the model. Essentially a VDM-SL specification.

NEW FUNCTION

```
class BM -- BoardModule
types
    public Board = set1 of PM`Piece
    inv s == forall p1, p2 in set s & p1 <> p2 => p1.position <> p2.position;

functions
    public move: Board * PM`Piece * PM`Coordinate -> Board
    move(board, piece, coord) == (
        let dead_piece = {p | p in set board & p.position = coord} in
            (board \ (dead_piece union {piece})) union
                {mk_PM`Piece(piece.type, coord, piece.color)}
    )
    pre piece in set board_state and coord in set PM`possible_moves(piece, board_state);
```

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NOT ABOUT THE GITHUB ISSUE

The principles transfer

Reasoning about a functional model:

- Referential transparency
- No global state
- (Arguably) easier to test

Downsides:

- Difficult to model stateful aspects - e.g. “castling”
- (Arguably) less readable

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OTHER TOPICS

Further topics of interest:

- Castling and the importance of real-world data
- Different testing techniques
- Implementing simple moves
- String manipulation for PGN

Questions?

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STILL BROKEN

```
PlantInv: set of Alarm * map Period to set of Expert -> bool
PlantInv(as,sch) ==
(forall p in set dom sch & sch(p) <> {}) and
  (forall a in set as &
    forall p in set dom sch &
      exists expert in set sch(p) &
        a.GetReqQuali() in set expert.GetQuali());

 --
        a.GetReqQuali() in set expert.quali
```