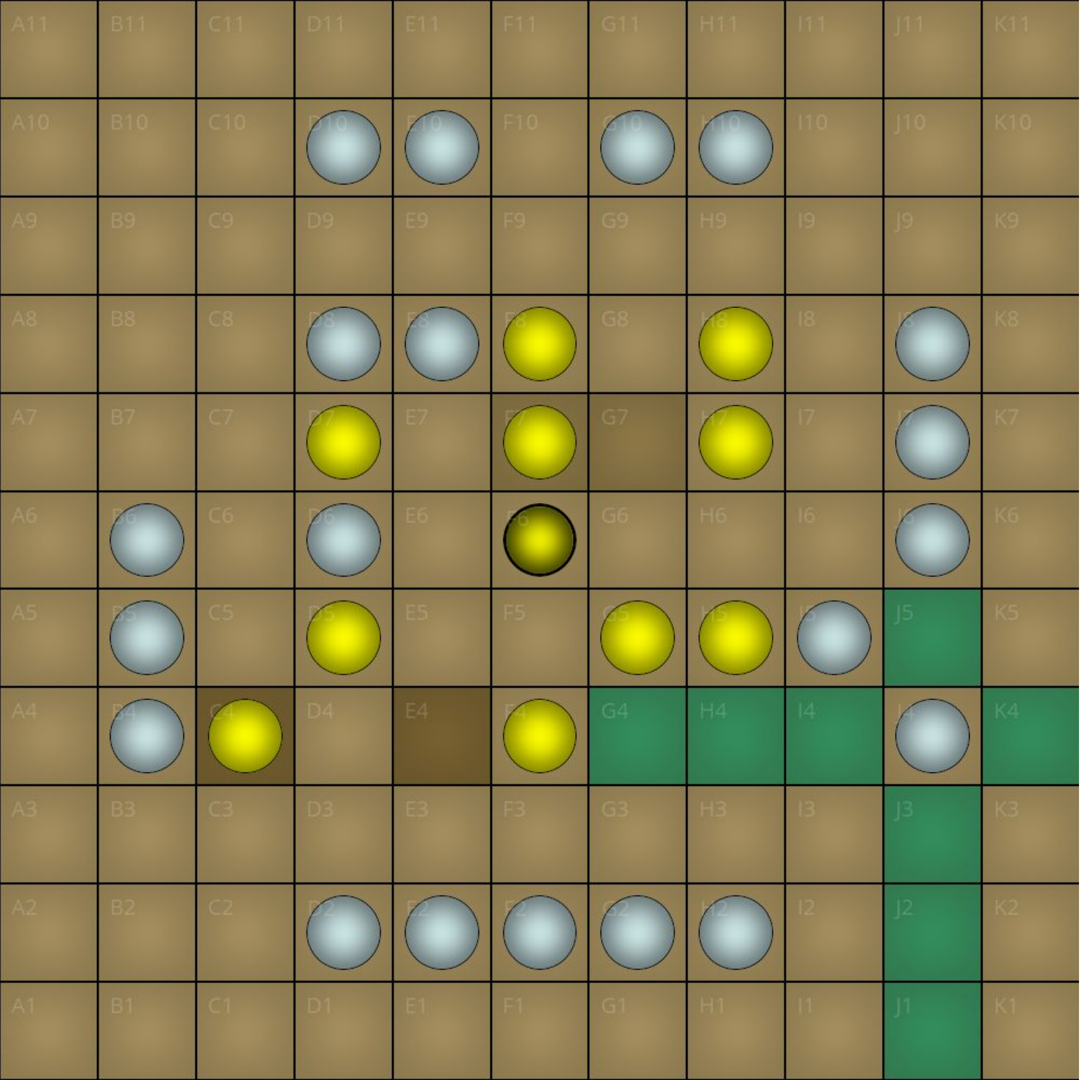
A11 B11 C11 D11 E11 F11 G11 H11 I11 J11 K11
A10 B10 C10 D10 E10 F10 G10 H10 I10 J10 K10
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A8 B8 C8 D8 E8 F8 G8 H8 I8 J8 K8
A7 B7 C7 D7 E7 F7 G7 H7 I7 J7 K7
A6 B6 C6 D6 E6 F6 G6 H6 I6 J6 K6
A5 B5 C5 D5 E5 F5 G5 H5 I5 J5 K5
A4 B4 C4 D4 E4 F4 G4 H4 I4 J4 K4
A3 B3 C3 D3 E3 F3 G3 H3 I3 J3 K3
A2 B2 C2 D2 E2 F2 G2 H2 I2 J2 K2
A1 B1 C1 D1 E1 F1 G1 H1 I1 J1 K1

Breakthru

Intelligent Search & Games
Lecturer Mark Winands
Project Submission
David Pomerenke

Structure

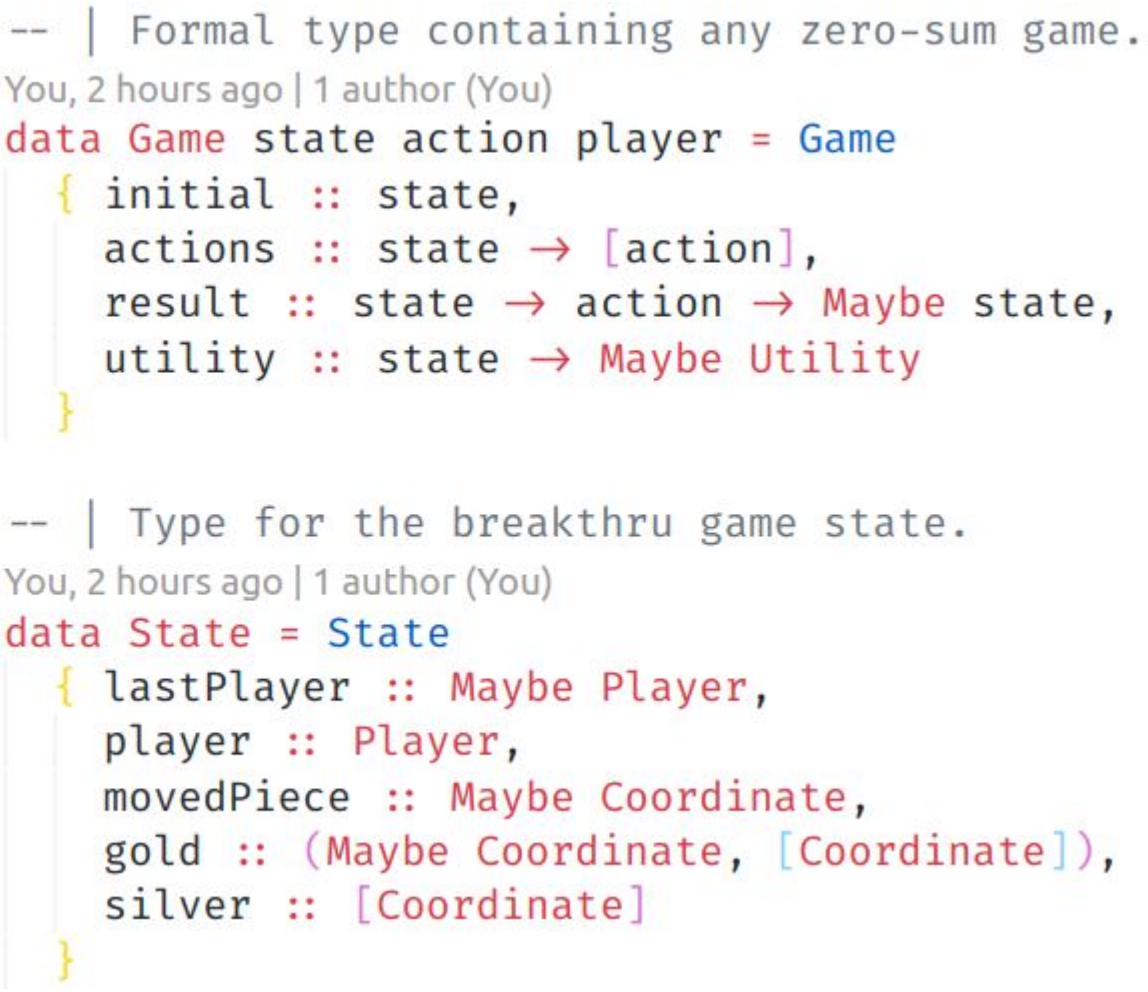
- Architecture
- Rules
- Agents
    - Random
    - Minimax
    - Alpha-Beta
- User Interface
- Evaluation
- Gameplay Demonstration

Architecture

- Elm Frontend /static
  - Display board, available actions
  - Animate movements & keep history
  - Query API for actions, results, AI moves (manual JSON)
  - Advantage: Correctness, rapid development
- Haskell Server /src
  - Provide API for actions, results, AI moves (automatic JSON)
  - Evaluation of agents
  - Advantage: High level, speed, parallelism
  - Disadvantage: Algorithms need to be rewritten
- Python Evaluation /evaluation
  - Visualize results

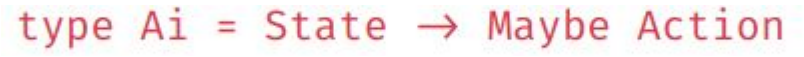
Rules

Game.hs



```
-- | Formal type containing any zero-sum game.
You, 2 hours ago | 1 author (You)
data Game state action player = Game
  { initial :: state,
    actions :: state → [action],
    result :: state → action → Maybe state,
    utility :: state → Maybe Utility
  }

-- | Type for the breakthru game state.
You, 2 hours ago | 1 author (You)
data State = State
  { lastPlayer :: Maybe Player,
    player :: Player,
    movedPiece :: Maybe Coordinate,
    gold :: (Maybe Coordinate, [Coordinate]),
    silver :: [Coordinate]
  }
```

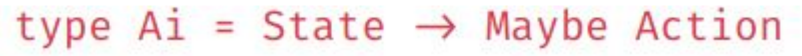
Agents



```haskell
type Ai = State → Maybe Action
```

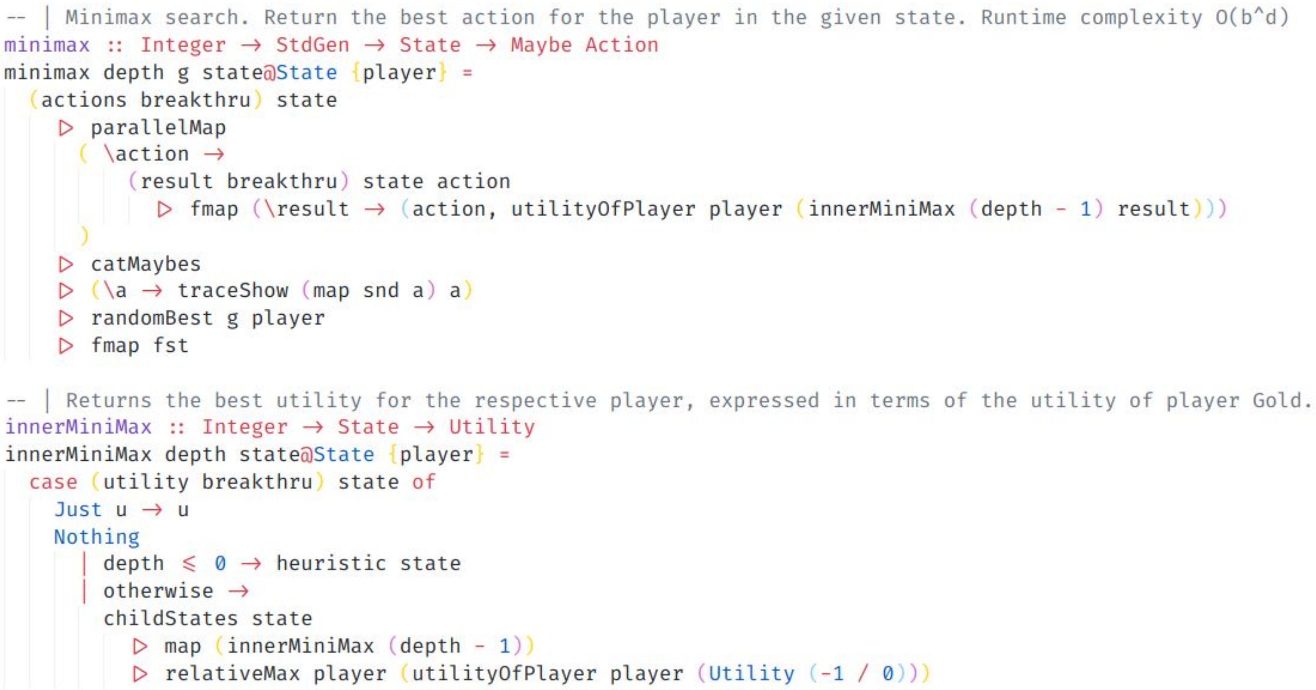
- Random (Helpers.hs)
    - Retrieve actions, select random element
    - Deterministic randomness
- Non-random
    - Evaluation function: #Gold / #max Gold - #Silver / max Silver

Agents



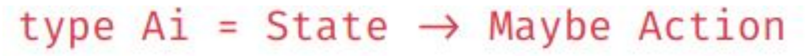
```
type Ai = State → Maybe Action
```

- Minimax (Minimax.hs)



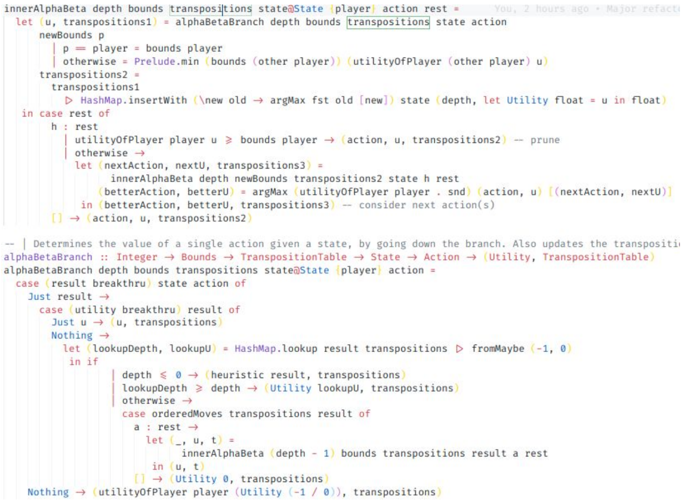
```
-- | Minimax search. Return the best action for the player in the given state. Runtime complexity O(b^d)
minimax :: Integer → StdGen → State → Maybe Action
minimax depth g state@State {player} =
  (actions breakthru) state
    ▷ parallelMap
      ( \action →
          (result breakthru) state action
            ▷ fmap (\result → (action, utilityOfPlayer player (innerMiniMax (depth - 1) result)))
      )
    ▷ catMaybes
    ▷ (\a → traceShow (map snd a) a)
    ▷ randomBest g player
    ▷ fmap fst

-- | Returns the best utility for the respective player, expressed in terms of the utility of player Gold.
innerMiniMax :: Integer → State → Utility
innerMiniMax depth state@State {player} =
  case (utility breakthru) state of
    Just u → u
    Nothing
      | depth ≤ 0 → heuristic state
      | otherwise →
        childStates state
          ▷ map (innerMiniMax (depth - 1))
          ▷ relativeMax player (utilityOfPlayer player (Utility (-1 / 0)))
```

Agents



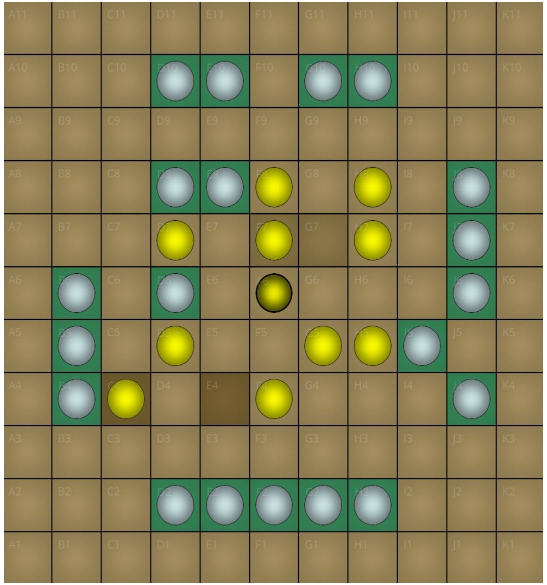
```
type Ai = State → Maybe Action
```

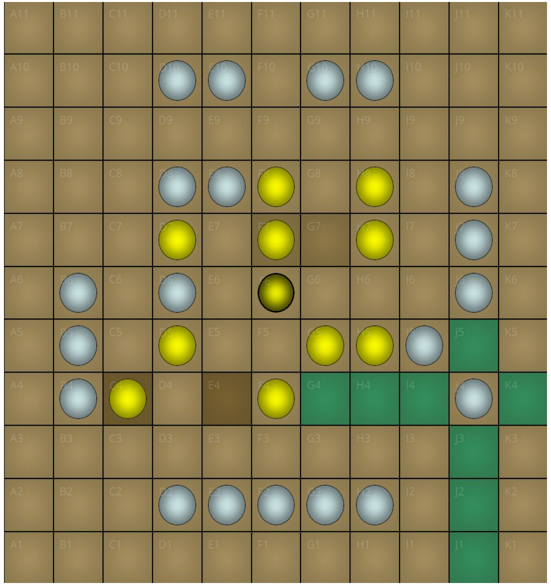
- Alphabeta (AlphaBeta.hs)
  - (John Hughes 1990: Functional implementation of AlphaBeta with laziness)
  - 2 parts
    - alphaBetaBranch: goes down one action
    - innerAlphaBeta: compares siblings and **prunes!**
  - Transposition Table
    - Generic hashing, no Zobrist hashing
  - Iterative deepening
  - Move ordering
  - ~O(b^d/2) instead of O(b^d)

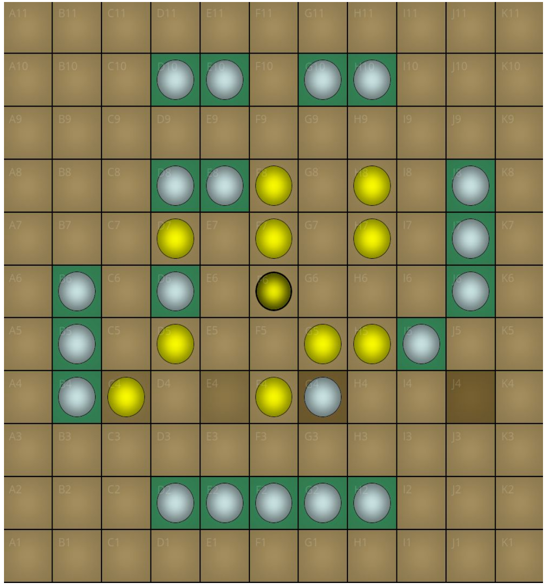


```
innerAlphaBeta depth bounds transpositions state@State {player} action rest =      You, 2 hours ago • Major refacto
  let (u, transpositions1) = alphaBetaBranch depth bounds transpositions state action
      newBounds p
        | p == player = bounds player
        | otherwise = Prelude.min (bounds (other player)) (utilityOfPlayer (other player) u)
      transpositions2 =
        transpositions1
          ▷ HashMap.insertWith (\new old → argMax fst old [new]) state (depth, let Utility float = u in float)
   in case rest of
        h : rest
          | utilityOfPlayer player u ≥ bounds player → (action, u, transpositions2) -- prune
          | otherwise →
            let (nextAction, nextU, transpositions3) =
                   innerAlphaBeta depth newBounds transpositions2 state h rest
                 (betterAction, betterU) = argMax (utilityOfPlayer player . snd) (action, u) [(nextAction, nextU)]
              in (betterAction, betterU, transpositions3) -- consider next action(s)
        [] → (action, u, transpositions2)

-- | Determines the value of a single action given a state, by going down the branch. Also updates the transpositi
alphaBetaBranch :: Integer → Bounds → TranspositionTable → State → Action → (Utility, TranspositionTable)
alphaBetaBranch depth bounds transpositions state@State {player} action =
  case (result breakthru) state action of
    Just result →
      case (utility breakthru) result of
        Just u → (u, transpositions)
        Nothing →
          let (lookupDepth, lookupU) = HashMap.lookup result transpositions ▷ fromMaybe (-1, 0)
           in if
                  | depth ≤ 0 → (heuristic result, transpositions)
                  | lookupDepth ≥ depth → (Utility lookupU, transpositions)
                  | otherwise →
                    case orderedMoves transpositions result of
                      a : rest →
                        let (_, u, t) =
                               innerAlphaBeta (depth - 1) bounds transpositions result a rest
                         in (u, t)
                      [] → (Utility 0, transpositions)
    Nothing → (utilityOfPlayer player (Utility (-1 / 0)), transpositions)
```

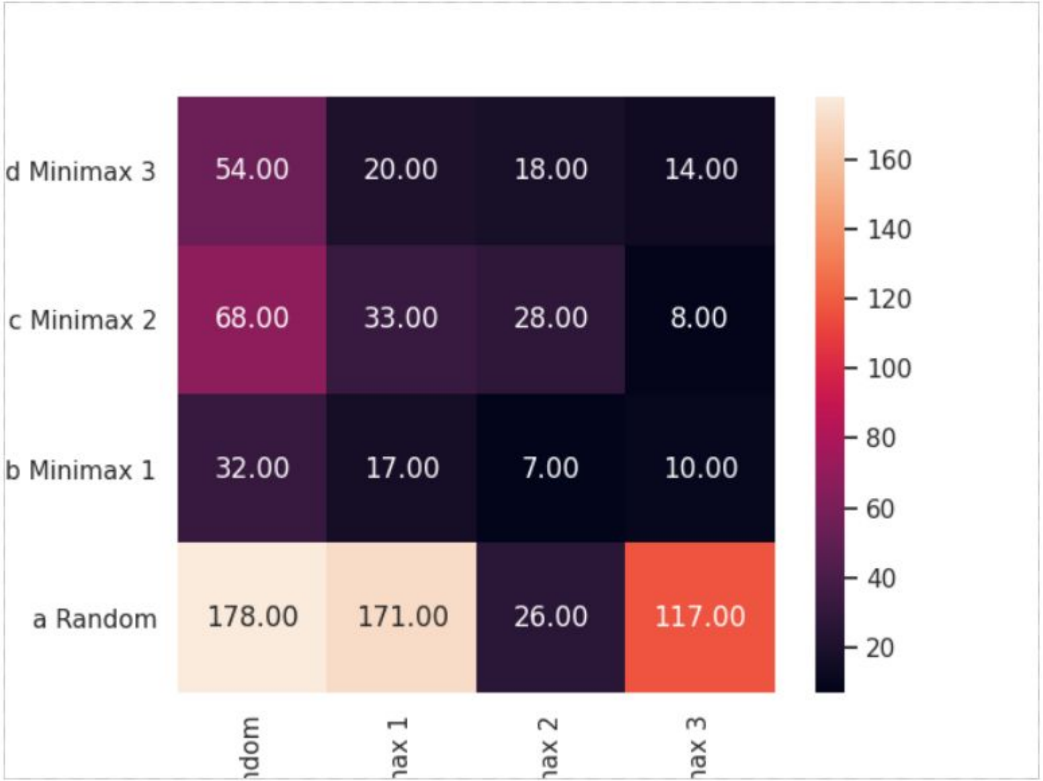
User Interface



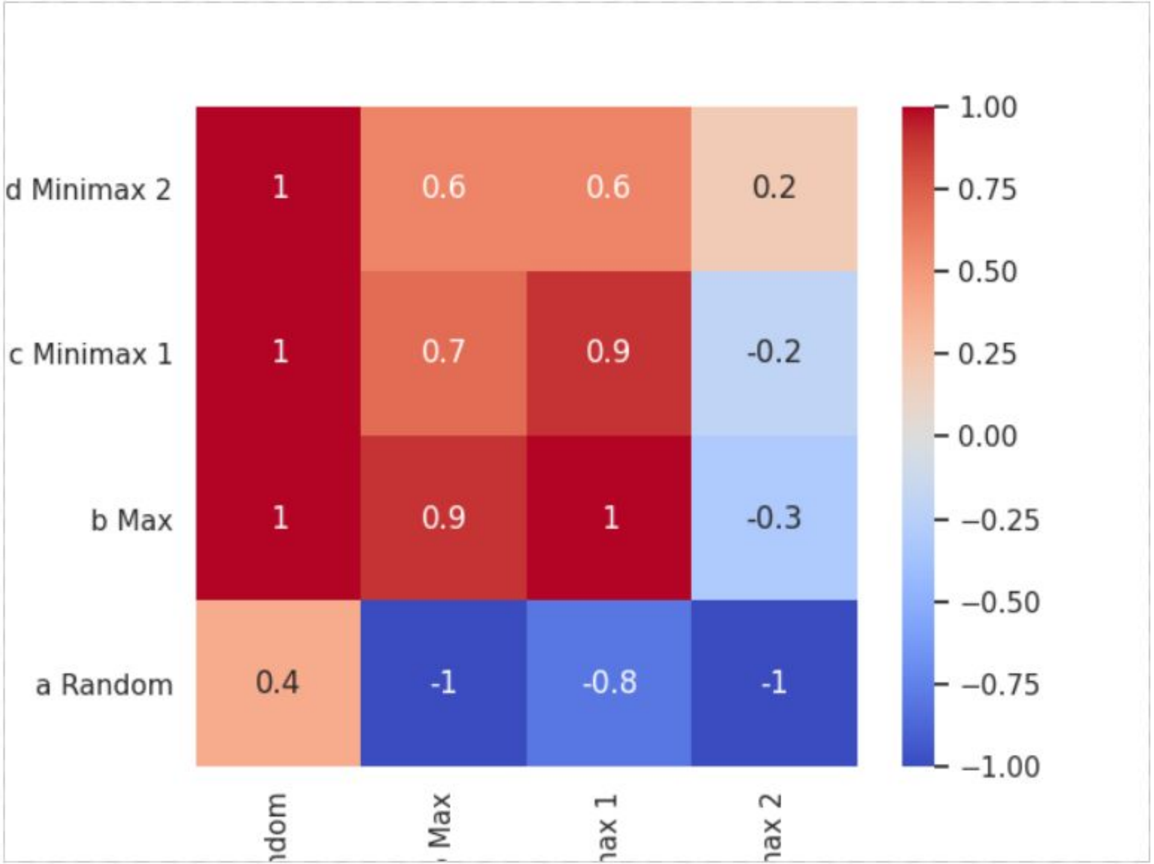




Evaluation (/evaluation/depth.png)



Evaluation (/evaluation/utility.png)



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