Mapping Chess Aesthetics onto Procedurally Generated Chess-like Games

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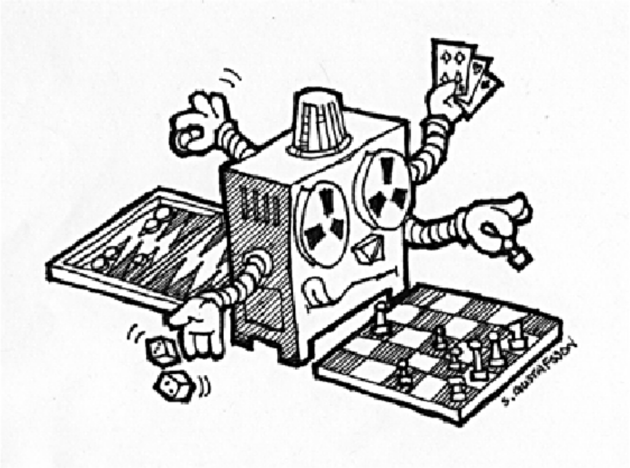
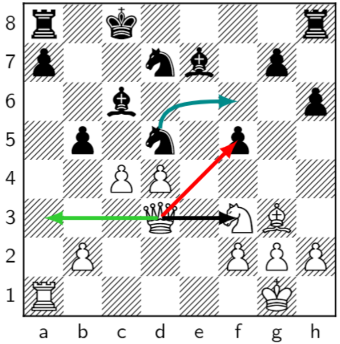
Background

Procedural Content Generation (PCG)

General Game Playing (GGP)



Simplified Boardgames (Björnsson, 2012)



- ♕d3-a3: $(-1,0,e)(-1,0,e)(-1,0,e)$
- ♕d3-f5: $(1,1,e)(1,1,p)$
- ♞d5-f6: $(2,1,e)$
- ♕d3-f3: ~~$(1,0,e)(1,0,w)$~~

```
P (0,1,e) + (-1,1,p) + (1,1,p) +
  (0,1,e)(0,5,e)(0,-4,e) + ... &
N (2,1,e) + (2,-1,e) + (-2,1,e) + (-2,-1,e) + (1,2,e)... &
R (0,1,e)^* + (0,1,e)^*(0,1,p) + (0,-1,e)^* + ... &
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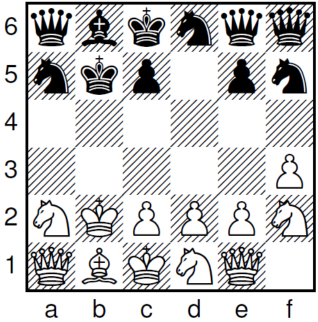
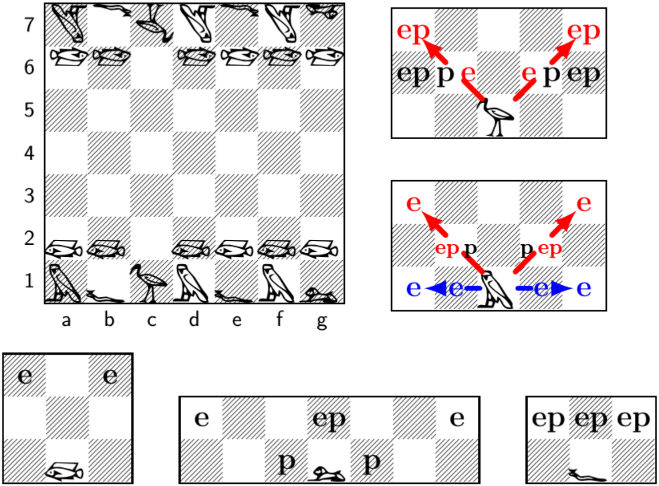
Motivation

Procedural Content Generation for GDL Descriptions of Simplified Boardgames (Kowalski, Szykuła; 2015)

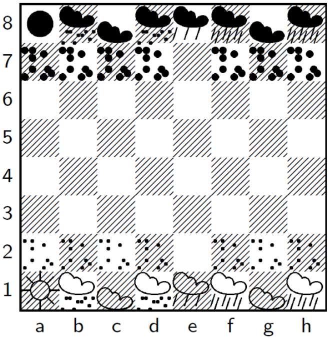


- ♙ Moves and captures 1 cell diagonally ahead.
- ♔ Moves and captures 1 or 2 squares straight ahead, jumping the intervening square in the case of moving 2 squares.
- ♘ Moves and captures 1 cell diagonally, and it can jump orthogonally forward by 2 squares if the destination is empty.
- ♗ Moves like the orthodox bishop, and it can move and capture 1 square straight ahead.
- ♕ Slides any number orthogonally if all pieces on the way are the opponent's, and it can capture and self-capture 1 case diagonally ahead, and move and self-capture 1 square straight-ahead, and 1 square straight-back.

Evolving Chesslike Games Using Relative Algorithm Performance Profiles (Kowalski, Szykuła; 2016)



Evaluating Chess-like Games Using Generated Natural Language Descriptions (Kowalski, Żarczyński, Kisielewicz; 2017)



(16)	Moves 1 backwards vertically Captures 1 forward vertically
(18)	Leaps 2 forward diagonally Captures 1 vertically or horizontally
(12)	Leaps 1 backwards diagonally Leaps forward over vector (1,2)
(8)	Leaps 2 forward vertically Leaps 1 vertically
(16)	Leaps 1 backwards diagonally Captures 1 horizontally or diagonally
(10)	Leaps 1 backwards diagonally Captures 1 diagonally

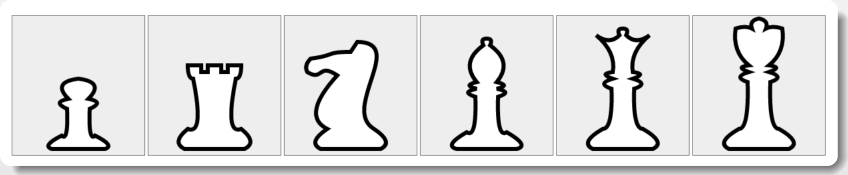
Goal

The shapes evolved for one game should look similar, so that they are easily identified as parts of a whole.

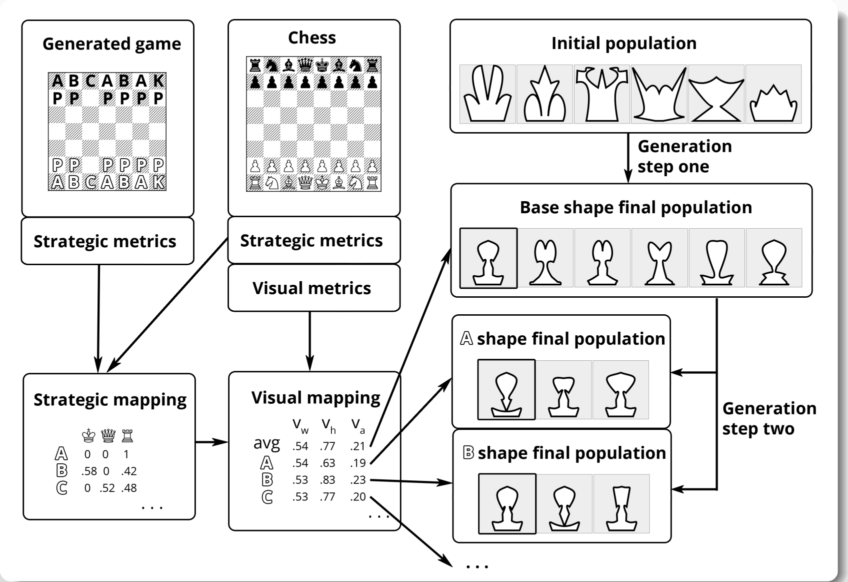
We would like the shapes of the pieces to correspond to their role and importance in the game.

Methodology

The piece shapes we know



Workflow


Generated game
Strategic metrics
Chess
Strategic metrics
Visual metrics
Initial population
Generation step one
Base shape final population
A shape final population
B shape final population
Generation step two
Strategic mapping
A 0 0 1
B .58 0 .42
C 0 .52 .48
...
Visual mapping
V_w V_h V_a
avg .54 .77 .21
A .54 .63 .19
B .53 .83 .23
C .53 .77 .20
...
...

Strategic metrics

- s_{po} The fraction of the piece occurrences in the game's initial state.
- s_{ec} The fraction of piece movements that end with a capture.
- s_{pw} This value is 1 if the piece can be used for a positional win, 0 otherwise.
- s_{cw} This value is 1 if piece can be used for a capturing win, 0 otherwise.
- s_{ba} The average ratio of the board area that can be covered by a piece from its initial position(s).
- s_{mr} The number of moves required to reach the most distant square from its initial position(s).
- s_{lm} The average number of legal moves for each reachable position on the board.
- s_{sd} The average shift distance for one letter, i.e. $\sqrt{\Delta x^2 + \Delta y^2}$.
- s_{dd} The average displacement distance for a word, i.e. $\sqrt{(\sum \Delta x)^2 + (\sum \Delta y)^2}$.

Strategic metrics

Values of strategic metrics for each piece in considered games.

metric	Chess						The Legacy of Ibis					The Weather Chess					
	♙	♘	♗	♖	♕	♔											
s_{po}	0.5	0.13	0.13	0.13	0.06	0.06	0.46	0.23	0.15	0.08	0.08	0.46	0.13	0.13	0.07	0.13	0.07
s_{ec}	0.66	0.5	0.5	0.5	0.5	0.5	0	0.25	0.5	0.6	0.5	0.5	0.75	0.5	0.5	0.75	0.66
s_{pw}	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
s_{cw}	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1
s_{ba}	0.55	1	1	1	1	1	0.1	0.50	0.7	0.82	1	0.13	1	1	0.13	1	0.5
s_{mr}	6	5	2	2	2	7	2	4	6	4	7	6	5.5	10	4	8	7
s_{lm}	2.48	5.25	8.75	14	22.7	6.56	1.16	3.92	2.49	3.95	3.55	1.75	4.63	2.84	2.5	4.81	3.06
s_{sd}	1.28	2.24	1.41	1	1.21	1.21	2.36	1.31	1.28	1.74	1.72	1	1.91	1.83	1.33	1.31	1.41
s_{dd}	1.28	2.24	5.66	4	4.8	1.21	2.36	2.27	1.28	2.31	1.72	1	1.91	1.83	1.33	1.31	1.41

Visual metrics

- v_w The ratio of the piece's width to the width of the drawing area.
- v_h The ratio of the piece's height to the height of the drawing area.
- v_a The ratio of the piece's area to the drawing area.
- v_{ta} The ratio of the piece's top 1/3 area to the piece's area.
- v_{ma} The ratio of the piece's middle 1/3 area (on the x axis) to the piece's area.
- v_s The intersection to union ratio between piece's left half and the (mirrored) right half; symmetrical shapes score 1 in this metric.
- v_{my} The ratio of the piece's middle half on the y axis to the piece's area.
- v_{tr} The area intersecting the piece and an upward-pointing triangle shape, over the piece's area.
- v_p The ratio of the piece's perimeter to double its bounding box perimeter.
- v_{sl} The ratio of the length of straight lines to the piece's perimeter.
- v_{sa} The ratio of sharp angles ($0°$–$60°$) to all angles between lines.
- v_{ga} The ratio of gentle angles ($120°$–$180°$) to all angles between lines.

Visual metrics

Values of visual metrics for each piece in considered games.

metric	Chess						The Legacy of Ibis					The Weather Chess					
	♙	♘	♗	♖	♕	♔											
v_w	0.45	0.59	0.52	0.54	0.52	0.52	0.55	0.54	0.53	0.53	0.55	0.54	0.53	0.53	0.53	0.52	0.45
v_h	0.52	0.8	0.82	0.63	0.90	0.98	0.81	0.63	0.83	0.77	0.83	0.63	0.76	0.75	0.78	0.98	0.53
v_a	0.12	0.29	0.18	0.19	0.20	0.26	0.23	0.19	0.23	0.20	0.24	0.19	0.20	0.19	0.20	0.26	0.12
v_{ta}	0.29	0.31	0.26	0.46	0.24	0.35	0.28	0.46	0.40	0.34	0.34	0.46	0.35	0.34	0.33	0.35	0.29
v_{ma}	0.28	0.31	0.29	0.18	0.29	0.25	0.30	0.18	0.22	0.24	0.26	0.18	0.23	0.25	0.24	0.25	0.29
v_s	1	0.77	1	1	1	1	0.91	1	1	1	0.94	1	1	1	1	1	1
v_{my}	0.84	0.73	0.88	0.73	0.85	0.83	0.82	0.73	0.79	0.79	0.78	0.73	0.79	0.82	0.80	0.83	0.85
v_{tr}	0.73	0.58	0.79	0.50	0.81	0.69	0.70	0.50	0.61	0.66	0.64	0.50	0.65	0.68	0.68	0.69	0.73
v_p	0.41	0.43	0.43	0.45	0.49	0.47	0.44	0.45	0.46	0.47	0.46	0.45	0.47	0.44	0.47	0.47	0.41
v_{sl}	0	0.04	0	0.29	0	0	0.02	0.29	0.12	0.14	0.08	0.29	0.15	0.11	0.12	0	0
v_{sa}	0.22	0	0.15	0	0.27	0.40	0.09	0	0.23	0.14	0.16	0	0.13	0.09	0.15	0.40	0.22
v_{ga}	0.33	0.6	0.38	0.29	0.33	0.33	0.50	0.29	0.32	0.31	0.42	0.29	0.31	0.35	0.32	0.33	0.33

Values for chess are computed from the Chess Shapes.

Values for the generated games are obtained by our algorithm – see next slides.

Mapping from general games to chess

We compare the functional properties of chess pieces and new generated pieces, and approximate the visuals of these new pieces based on the visuals of their closest chess pieces.

- How is the functional similarity of pieces in different games with different rulesets assessed?
- Can a generated piece be similar to more than one chess pieces, and how is that handled?

Calculating distance between pieces

Straightforward approach

Euclidian distance treating the nine strategic features as a 9-dimensional vector

Concerns

- Ignores that the pieces belong to different games.
- Not all strategic measures are in the same value range

Improved approach

Standardization to z-scores: processes a raw feature value x as $z = (x - \bar{x})/\sigma_x$ where $\bar{x}$ is the mean value of all pieces in the same game and σ_x is the standard deviation of those values.

- This standardization ensures all metrics are in the same value range and clearly denotes outliers.

Calculating closest chess pieces

Possible options

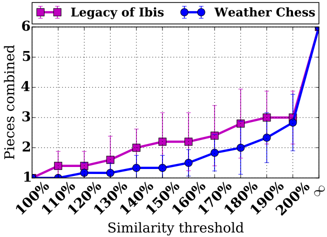
- Choose only the closest piece and use its visuals
  (often maps multiple pieces into one chess piece)
- Use all visuals based on the proportional distances
  (this results in very similar target metrics for all pieces)
- Consider only some of the closest chess pieces
  (how to calculate that?)

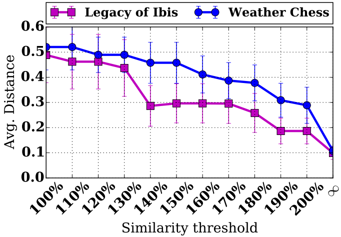
Calculations

- Divide the distance between the new piece and a chess piece with the distance to the closest chess piece.
- Values close to 1 means high similarity to the new piece as the closest chess piece.
- Need some threshold value to distinguish "similar enough" pieces.
- Normalize weights above threshold so they sum up to 1.

Choosing threshold

Sensitivity of the chess piece mapping to different thresholds.





The threshold is the highest distance ratio of the closest chess piece that is considered "similar enough". Results are on average number of shapes combined and average pairwise visual distance.

Calculations

We chose to consider only pieces with a strategic distance at most 160% that of the closest chess piece ($W_i \geq 0.625$).

Pieces mapping

Weight of chess pieces in terms of strategic similarity to other pieces

	♙	♘	♗	♖	♕	♔
		0.42	0.58			
				1.00		
				0.42		0.58
				0.48	0.52	
		0.29		0.24	0.20	0.28

	♙	♘	♗	♖	♕	♔
				1.00		
				0.52	0.48	
			0.61	0.39		
				0.42	0.58	
						1.00
	1.00					

Representation

- Generated shapes encoded in Scalable Vector Graphics (SVG) format.
- The genotype is a series of lines (encoded in an array) that may contain straight lines, quadratic Bézier curves, and cubic Bézier curves.
- The starting point of every line is the end point of its predecessor.
- The drawing area has been set to 200×200 units.
- The first point of every shape is placed on the lowest horizontal line.
- The first point is automatically connected to the last point, closing the shape.
- When a piece is flagged as symmetric, we assume the array represents only the right half of the piece (left half is mirrored).
- For asymmetric pieces, its genotype explicitly contains all parts of the shape.

Evolution

- Tournament selection choses $n/2$ pairs as parents
- Crossover produces 2 children, then mutation
- Removing inconsistent individuals
- Removing too similar shapes (fraction of intersecting area to the union area)
- Best n shapes from parents and children

Crossover

- Cuts the array of parents in half and join the halves
- Use asymmetric representation of a parent when needed

Mutation

- Convert piece to asymmetric, or
- Choose one of the lines and
  - modify line type,
  - split straight line in half,
  - transform lines' points by a random vector.

Evolution variants

Independent evolution

- For each piece, evolve a population towards its target.
- The fitness is the Euclidean distance in the space of visual metrics.
- The best individual in each population is chosen.

One-step evolution

- Evolve a population towards the average of all pieces' target values.
- Choosing most-fitting shapes for each piece
- Similarity check forbidding the same shape to be chosen twice.

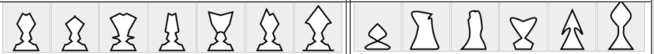
Two-step evolution

- For each piece initialize a new population consisting of the fittest individual from one-step variant.
- Perform shallow evolution towards its target for each piece individually.
- The best individual in each population is chosen.

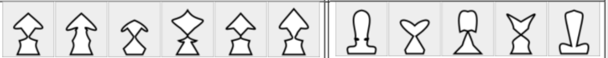
Results

Experiment setup

- We tried to (re)generate shapes for chess, The Legacy of Ibis, and The Weather Chess.
- Initial run with randomized parameter sets
  - deep (200–400 generations, population size 40–100),
  - or wide (50–200 generations, population size 200–500);
  - the second step of evolution ran for 1–10 generations.
- Three ways to initialize the population:
  - copies of a triangle shape,
  - copies of chess pawns,
  - random shapes.
- For statistical comparisons between approaches, games and initial shapes:
  - 20 independent evolutionary runs on each combination,
  - Population size 100,
  - 100 generations,
  - second step with 10, 20, and 50 generations.



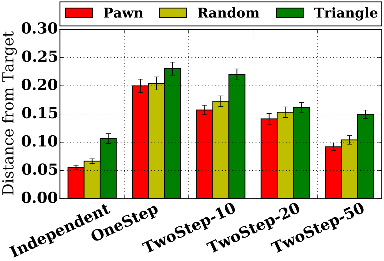

init	avg.	♙	♘	♗	♖	♕	♔	♙	♘	♗	♖	♕	♔
	Two-step evolution variant							Independent evolution variant					
△	1.06	1.07	1.08	1.09	1.03	1.06	1.11	0.54	0.06	0.45	0.55	0.52	0.59
RANDOM	0.46	0.55	0.32	0.48	0.61	0.52	0.62	0.61	0.24	0.47	0.58	0.56	0.67



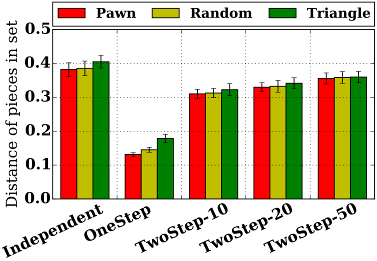

init	avg.										
	Two-step evolution variant						Independent evolution variant				
△	0.14	0.16	0.41	0.18	0.18	0.11	0.16	0.41	0.16	0.20	0.09
RANDOM	0.12	0.18	0.33	0.15	0.14	0.14	0.16	0.46	0.16	0.17	0.11


init	avg.												
	Two-step evolution variant							Independent evolution variant					
△	0.31	0.45	0.39	0.30	0.0.33	0.49	0.42	0.53	0.31	0.30	0.31	0.52	0.09
RANDOM	0.29	0.44	0.34	0.26	0.32	0.36	0.23	0.53	0.32	0.36	0.33	0.56	0.09

Statistical comparisons



Distance from Target Values



Distance within the same game

Figure: Results are collected from 20 runs per game, initial shape, and method.

- Independent evolution closely matches desired values, but pieces are very different from each other.
- For the one-step evolution it is the opposite, yet few steps of the second phase are enough to introduce a significant divergence.
- Pawns are the best starting shape.

Summary

Summary

We described a method for evolving shapes of chess-like pieces that belong to a number of previously generated games.

This initial attempt focuses on making them visually pleasing and playable.

- Mapping the visual aesthetics of chess pieces to their in-game function.
- Preprocessing required to identified the role of a piece in an arbitrary game.
- Estimating the intended visual aesthetics of new games' pieces based on their role for this particular game.
- Results encoded as SVG images.

Discussion

Goal

Sets of shapes can be distinguished as belonging to the same game.

When using on-step or two-step evolution variant, the generated sets usually contain large-enough common theme to distinguish them from the others.

Although, generated piece sets may contain too similar pieces.

- Our similarity tests remove the most obvious cases.
- Yet area coverage test is sometimes not enough.
- Multiple pieces can still easily mistaken by human players due to common visual details.

Independent evolution creates piece shapes which are not correlated, so it does not fulfill this goal.

Discussion

Goal

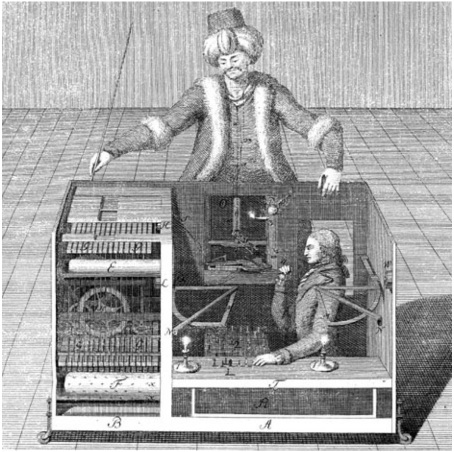
Shapes of individual pieces should intuitively correspond to their role and importance in the game.

The degree to which the goal is fulfilled is more disputable.

- Chess-based grounding achieves its stated aim in some cases.
- It is hard to unambiguously decide what style should characterize a piece given its rules
- The mappings to chess pieces based on strategic similarities gives results that can be justified.
- However, the process of evolution itself usually blurs all differences that are not close to extremes.

Future work

- Analyze and improve on the strategic and visual metrics for a better mapping and a more concrete visual identity, respectively.
- Improve the algorithm in order to better achieve both goals at the same time
- Improve similarity assessment.
- Introduce novelty search.
- Explore the use of similar techniques for other games, including other board games or even digital games.
- Combine with previous results to develop a system that can procedurally generate, on demand, games together with their rule explanations and their full visuals.



Thank you