Embed the Rules

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This article examines the concept of embedding the rules of a game in its equipment, as a general pattern for good game design. Several examples demonstrate the benefits of doing so. An analogy is drawn with the Japanese concept of poka-yoke, or mistake-proofing, in manufacturing design.

1 Introduction

THIS series on *Game Design Patterns* aims to explore fundamental principles that encourage good game designs. While this term is reminiscent of the 'game programming patterns' described in the book of the same name [1], its use there refers to software programming practices in video game development, whereas a 'game design pattern' here refers to any practice that encourages good designs in games and puzzles.[1] This first installment in the series looks at the concept of embedding the rules in the equipment.

To 'embed the rules' means to use relevant features of the game's physical components (board, pieces, environment, etc.), to enforce implicit rules which then do not need to be explicitly stated to players. This might also be described as 'hiding the rules in the equipment', or phrased as an aphorism: *hide the forest in the trees.*[2]

This approach can have significant benefits when designing games, including: simplifying rule sets; minimising player error; handling degenerate geometric cases; allowing the emergence of implicit strategies; providing tutorial assistance to players; and so on. These benefits are examined in the following sections, through example.

2 *Poka-Yoke*

Simpler rule sets generally reduce the incidence of player misinterpretation or error – provided that no crucial information is simplified out! – and lead to more conceptually elegant games [2]. Simpler rule sets also have the significant benefit of giving the player less information to remember, allowing them to concentrate instead on strategic planning and actually *playing* the game, rather than the mundane bookkeeping of calculating which moves are legal or not. The trick is to simplify the rules as much as possible, while ensuring that the game remains complex enough to be interesting.

For example, consider the Heptalion puzzle shown in Figure 1, in which the aim is to place the five tiles, each showing a pair of symbols, to exactly cover the set of matching symbols on the left [3]. These rules are trivially simple and instantly intuitive; no player who has played the game should ever need to reread them.

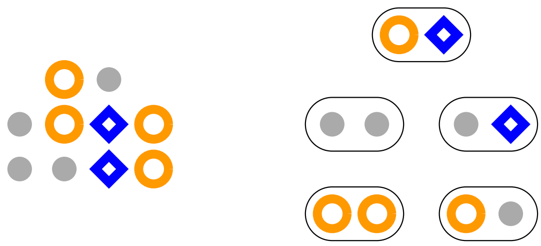

Figure 1. A Heptalion challenge and pieces.

Despite its simplicity, this design is actually the result of considerable thought and effort by its designer Néstor Romeral Andrés, as described in the article 'Heptalion' in this issue. This is a case of embedding the rules in the components (i.e. the two patterns on each tile must be played as a pair, symbols must match identical symbols, etc.), making the game so intuitive that misinterpretations and mistakes are almost impossible.

Romeral Andrés makes the astute observation that this process of mistake-proofing is an instance of *poka-yoke*.[3] This is a Japanese term that refers to any mechanism in a manufacturing process that helps an equipment operator avoid (*yokeru*) mistakes (*poka*), by drawing attention to human errors as they occur [4]. In the context of game design, *poka-yoke* can be seen as the concept of reducing player error, by simply making the equipment not allow such mistakes to occur in the first place, either explicitly or implicitly through its design.

[1] The concept of 'design patterns' was introduced in 1977 by Christopher Alexander in the context of architecture.
[2] Proposed by Richard Reilly, personal correspondence, 12 June 2015.
[3] Romeral Andrés first came across the concept of *poka-yoke* when researching the asymmetric design of the VGA plug that virtually eliminated incorrect dockings by users. If only the USB design committee had learnt from this lesson!

Browne, C., 'Embed the Rules', *Game & Puzzle Design*, vol. 1, no. 1, 2015, pp. 60–70.

2.1 Explicit Embeddings

Rules can be *explicitly embedded* in the equipment to achieve *poka-yoke* (mistake-proofing). Consider Ploy, shown in Figure 2, which is an early example from 1970 [5]. The markings on each piece act as instructions that indicate direction and distance of travel; each piece can move in the direction of one of its markings, a number of cells up to its total number of markings.

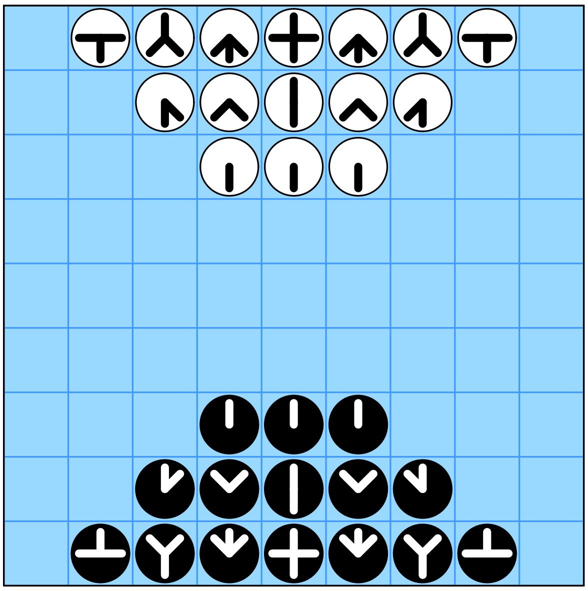

Figure 2. A game of Ploy about to start.

Such visual cues have been embedded in the pieces of many games since then. The designs on the Mijnlieff[4] pieces, shown in Figure 3, intuitively indicate where the next player must move relative to the piece just placed: orthogonally in line, diagonally in line, adjacent, or nonadjacent.

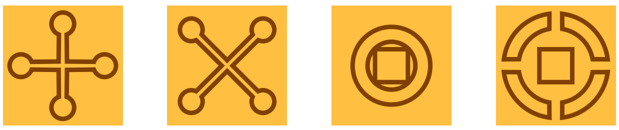

Figure 3. The four Mijnlieff piece designs.

The 5×5 *icon grid* embedded in pieces of The Duke,[5] shown in Figure 4, explicitly show the player what actions each piece can perform, and where. Navia Dratp [6][6] uses a similar mechanism, while Confusion: Espionage and Deception in the Cold War [6] subverts this idea by showing movement rules on the pieces, initially visible *only to the opponent*, that must be deduced through play.

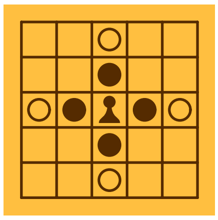

Figure 4. Visual cues on a piece from The Duke.

Visual cues may also be embedded in the board, to constrain piece movement intuitively. For example, each square in the child's board game Smess: The Ninny's Chess [7] is marked with arrows showing valid directions of travel. Similarly, the 1972 game Trippples [6] involves 64 tiles each showing three directions of travel (Figure 5), which the players alternately place in an 8×8 square grid to form the board for each game. However, players' movements are not decided by the arrows under their own pieces but under their *opponent's* pieces instead, in a twist that is both *poka-yoke* and counterintuitive at the same time.

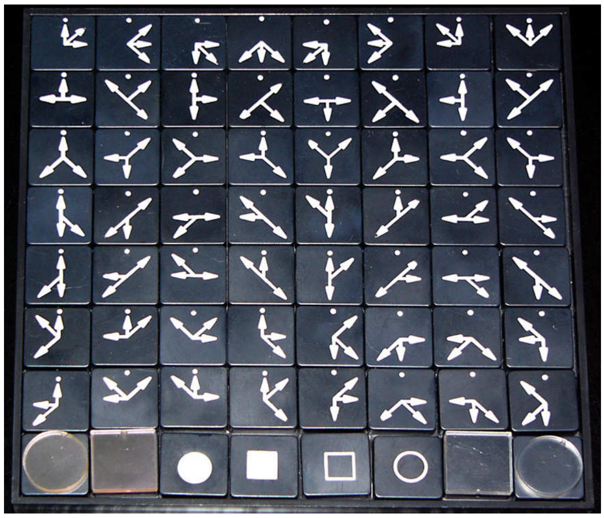

Figure 5. Directional tiles of the Trippples board.

Abstract rules involving concepts other than movement can also be *semantically embedded* in the equipment, e.g. by stating them on playing cards. There are many examples of this in popular card games such as Magic: The Gathering [6] and Dominion [6] (Figure 6), in which the cards describe the actions available to players. Even the Chance and Community Chest cards in Monopoly [6] explicitly state instructions for the players, which they do not need to memorise – or even worry about – until each card is drawn.

[4]http://www.mijnlieffgame.com/welcome
[5]http://www.catalystgamelabs.com/casual-games/the-duke
[6]I will use the *BoardGameGeek* online board game database as a catch-all reference for games mentioned in passing.

Figure 6. Dominion card 'Witch' by Matthias Catrein, © 2008 Rio Grande.

The standard deck of 52 playing cards also demonstrate mistake-proofing in their rotationally symmetrical illustrations. Players' cards are always the right way up in their hands regardless of what orientation they were drawn in, otherwise many would be upside down when drawn.

A superb example of *poka-yoke* can be found in the puzzle game Tantrix.[7] The Tantrix set consists of 56 hexagonal tiles showing all ways in which the tile sides can be joined by paths of four colours, such that each tile includes paths of three different colours (except for three straight lines connecting opposite sides).

The Tantrix tiles are numbered 1 to 56, such that each tile has a number on its back in one of the path colours (Figure 7, top). This allows the tiles to be used for a number of puzzle challenges, in addition to the standard game. Starting with the first three tiles, the number 3 is yellow, so the player's first challenge is to form a closed yellow loop with those three tiles (Figure 7, bottom). Then the next number 4 is red, so the player's next challenge is to form a closed red loop with those four tiles, and so on, up to tile number 10.

The Tantrix set therefore embeds a set of puzzle challenges within its equipment, by judicious numbering and labelling of the component pieces. Further, each challenge is mistake-proof, without the need for explicit additional rules, as the piece describing each challenge shows the number of tiles required and the colour of the target path.

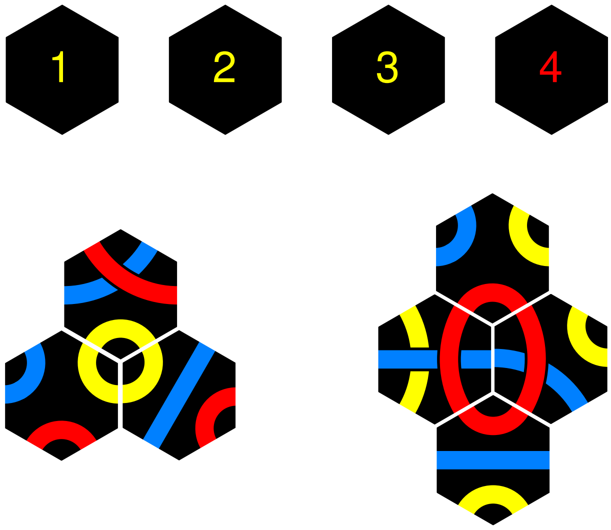

Figure 7. The backs of the first four Tantrix tiles (top) and the first two puzzle challenges (bottom).

2.2 Implicit Embeddings

Rules can also be *implicitly embedded* in the equipment to achieve *poka-yoke*, typically by the shape of the board and pieces, without the need for further visual decoration.

Figure 8 shows a game of Tixel[8] in progress. Tixel pieces are designed with a circular concavity on one side, so that some can rotate in-place in 45 degree increments while others are blocked from rotating, depending on the placement and orientation of the surrounding pieces. This mechanism simplifies the rule set and enforces this potentially confusing constraint in a clear, intuitive way.

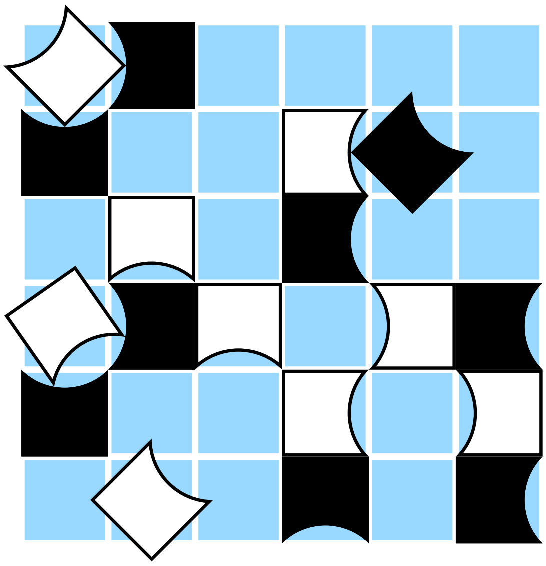

Figure 8. A Tixel game in progress.

[7] http://www.tantrix.com
[8] http://www.nestorgames.com/#tixel_detail

Christian Freeling's Loonybird Chess, from 1983 [7], shows how existing tropes can be exploited to create new hybrid pieces with implicitly defined movements. The cardinal pieces in the Loonybird Chess set consist of two parts, an upper *hunter* and a lower *carrier*, and take on the role of each part depending on whether they are moving or capturing, respectively.

Figure 9 shows a white 'knight-rook', which moves like a knight but captures like a rook, and a black 'knight-bishop', which moves like a knight but captures like a bishop. Players familiar with Chess will immediately understand the movements of these unusual pieces, despite not having seen them before, without having to memorise new rules (beyond the upper/lower distinction).

Figure 9. Two Loonybird Chess pieces (photo by Christian Freeling).

Piece size is another property used for implicitly embedding rules in the equipment. It dictates: movement in Alapo [6]; power in Oshi [6]; capture in Gobblet [6]; and various properties in many games playable with Looney pyramids.[9]

The game Terrace [8], shown in Figure 10, implicitly exploits both board and pieces, allowing relatively simple and intuitive rules. Piece size dictates direction of capture (creating the attractive property of *asymmetric capture*), while the contours of the terraced board constrain movement. Terrace was considered innovative and 'futuristic' when it was released in 1991, appearing as a frequent prop on the television series *Star Trek: The Next Generation*. Imagine its impact if it had been released when first invented in 1950.

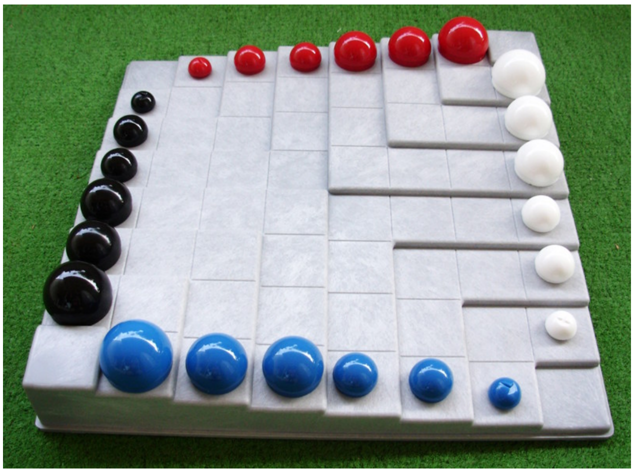

Figure 10. A game of Terrace ready to start (photo by Geni Palladin [6]).

Implicit rules may also be delegated to external sources, such as the word game Scrabble [9] (which has enough rules of its own) tapping the players' cultural knowledge of language to define which letter combinations are valid and which are not. This outsourcing of rules to an external authority brings a huge richness but also ambiguity to the game, depending on the players' language, level of vocabulary, dictionary being used, level of competition, etc., necessitating the creation of explicit word lists for official play.

Roleplaying games are another example of the delegation of rules, but this time to the players themselves. Given a basic premise and some fundamental rules to work within, the players control the direction of play through their understanding of the hypothetical game world, and their own interpretations of what actions can and cannot be legally (and sensibly) performed within it.[10]

3 Tutorial Help

Another benefit of embedding the rules in the equipment is as a tutorial device for players. Consider the ancient Japanese game of Shogi [10], shown in Figure 11, which has a notoriously high barrier to entry for new players.

Shogi pieces exhibit some degree of mistake-proofing in their design, as they are pentagonal in shape with an apex that points towards the opponent, to clarify whose pieces are whose. But players must recognise the *kanji* characters on each piece and remember their associated movements, and must deal with the fact that captured pieces are reentered onto the board as the opponent's.

[9] http://www.looneylabs.com/looney-pyramids
[10] Based on an observation by Richard Reilly, personal correspondence, 19/6/2015.

Figure 11. Shogi pieces (Ishi Press International Edition, photo by Michael Kandrac).

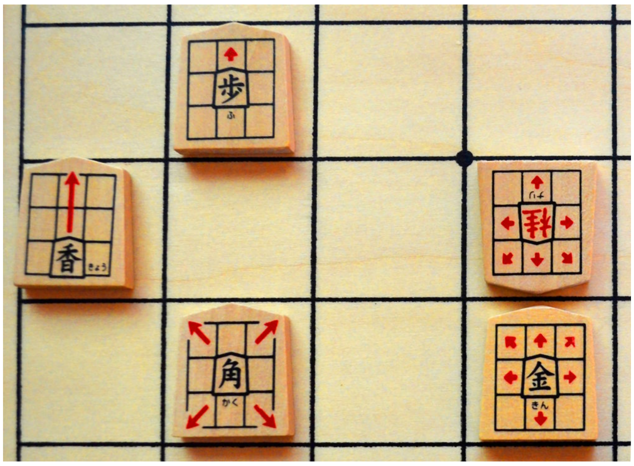

Figure 12. Kumon 'Study Shogi' set (photo by Mike Fogus).

Figure 13. Hidetchi's Internationalised Piece Set from Nekomado (photo by Russ Williams).

A number of publishers have sought to reduce this learning curve by showing piece movement visually on the pieces themselves, such as the Kumon 'Study Shogi' set shown in Figure 12. Note that these pieces still show their original *kanji* glyphs, so are primarily tutorial aids.

Figure 13 shows another approach to helping new players learn Shogi, through known iconography rather than explicit instruction. Pieces show icons of familiar Chess pieces where possible, with the more exotic pieces (specific to Shogi) represented by icons in a compatible aesthetic style, that should not be hard for a Chess player to learn.

Similarly, players who have trouble remembering the movement rules in Robert Abbott's popular Chess variant Ultima [7] can play with a tutorial set, in which each piece shows an icon of its closest Chess equivalent, decorated with additional cues as needed. Figure 14 shows such a pictographic piece set by Fergus Duniho.[11]

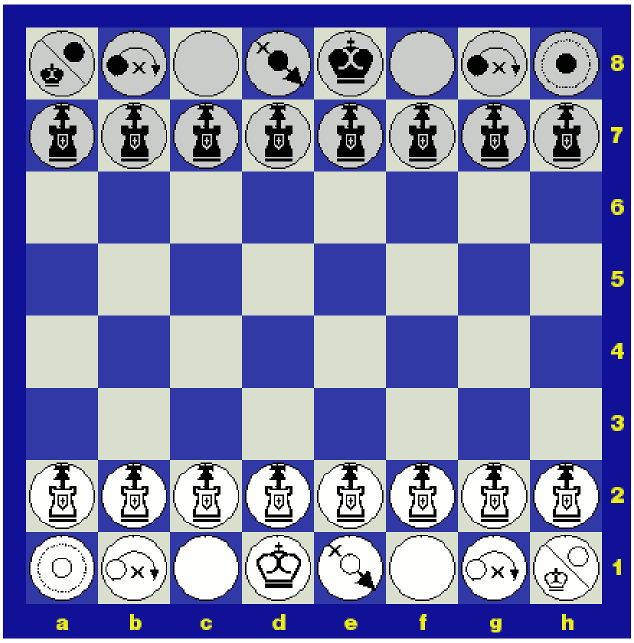

Figure 14. Pictographic version of Ultima pieces, © 2001–2014 Fergus Duniho.

4 Emergent Strategies

It is a natural bonus for the designer – and players! – if emergent strategies occur in a game, as a side effect of the interplay between the equipment, rather than due to explicitly stated rules.

[11] http://play.chessvariants.org/pbm/play.php

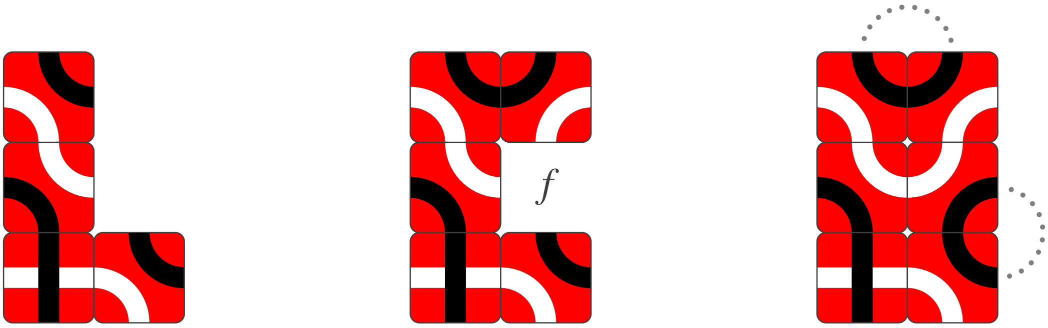

Figure 15. A Trax position, showing forced move *f* that guarantees a win for Black.

Consider the Trax[12] position shown in Figure 15. Trax is already an elegant and *poka-yoke* game, as both players share a single tile type, with two distinct sides, on which coloured paths visually define the connectivity for each player. However, the geometry of this tile design created a problem, as holes surrounded by tiles on all four sides could too easily become unplayable, if those four sides did not have two path ends of each colour.

To fix this problem, the game's designer, David Smith, introduced a *forced move* rule that ended up adding a new dimension of strategy.[13] Consider the move shown in Figure 15 (middle), which creates a three-sided gap *f*. There is only one tile orientation that will match the three exposed path ends, so that tile orientation must be played there as part of the move (right). Such forced moves can trigger other forced moves, and so on, to achieve complex and interesting results with a single move.

Smith did not specifically design for this strategy, it emerged as a natural consequence of the game's geometry. But once players know this rule, it is then the equipment itself that explicitly defines such forced moves.

Trax is also interesting in that it has both an intuitive 'form a closed loop' goal, as well as a more arbitrary 'connect opposite sides of a virtual 8×8 grid' goal. The intuitive goal is almost mistake-proof, while the arbitrary goal can be confusing for players, as it relies on external rules outside the equipment.

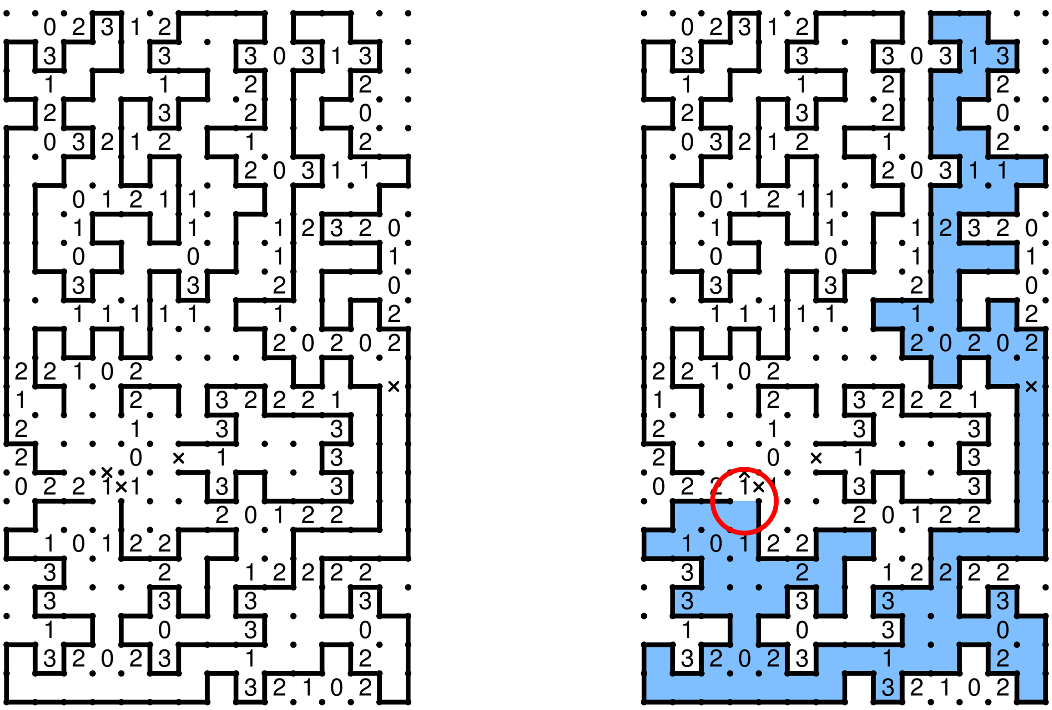

Figure 16. A partially solved Slitherlink challenge (left) is more comprehensible after region colouring (right).

[12]http://www.traxgame.com

[13]Personal correspondence, 9 March 2015.

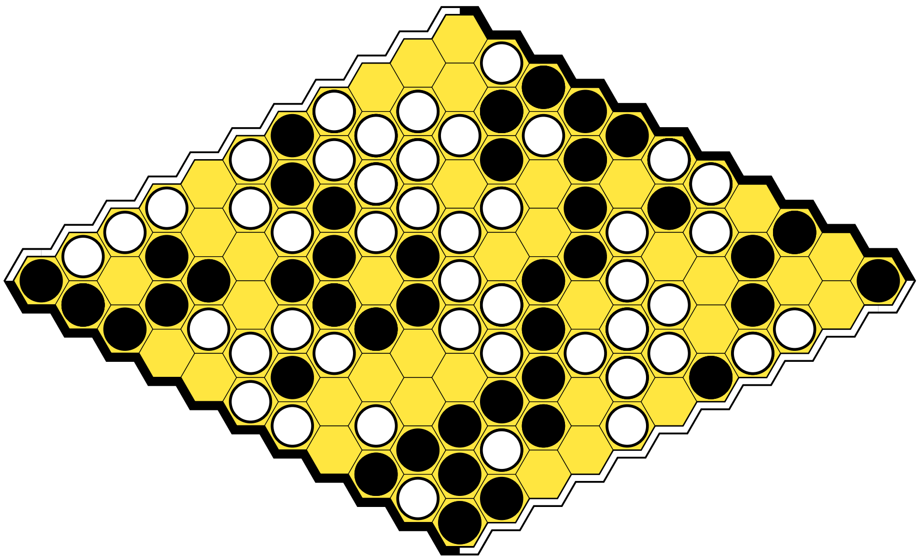

Figure 17. A game of Hex won by Black, who has connected the black sides with a chain of black pieces.

Figure 16 shows another case of a strategy emerging from the inherent geometry of a game. This case involves the deduction puzzle Slitherlink, in which the solver must trace a *simple* (i.e. closed and non-self-intersecting) path through the orthogonal vertices of a square grid, to visit the number of sides indicated on each numbered cell. This particular instance is challenge #57 from [11].

Figure 16 (left) shows the challenge mostly completed, with a few loose path ends, but it may be confusing for readers not experienced with Slitherlink to deduce where to proceed from here. However, we can turn to mathematics and exploit the Jordan Curve Theorem to give some insight into the problem. This theorem states that any simple curve has an inside and an outside, and any cross-section completely through it will cross its boundary an even number of times [12].

We can, therefore, colour regions of the grid that *must* lie inside the final path, as shown in Figure 16 (right), which immediately provides the next move to make; the circled path ends must deviate away from each other and not join, otherwise the coloured region would be illegally cut off. Another strategy allowed by the Jordan Curve Theorem is that any horizontal or vertical line through the grid must intersect an even number of edge segments, which can provide crucial additional information when solving complex challenges.

Mathematics, and geometry in particular, is a rich source for embedding implicit rules and constraints into equipment. Consider the connection game, Hex, shown in Figure 17, in which players take turns adding a piece of their colour to an empty cell, and aim to connect their sides of the board with a chain of their pieces [1].

This simple rule set belies the strategic depth of Hex, as the mere inclusion of the concept of 'connectivity' brings with it a whole slew of implications. As software engineer Phil Bordelon says: *it's like you get extra rules for free* [1, p. 347].

However, it is possible to achieve an even simpler rule set, with comparable depth, through a slight change in board design. In the early 1950s, computer pioneer Claude Shannon proposed the game of Y, shown in Figure 18, in which players aim to connect all three sides of a triangular grid of hexagons with a chain of their pieces [1].

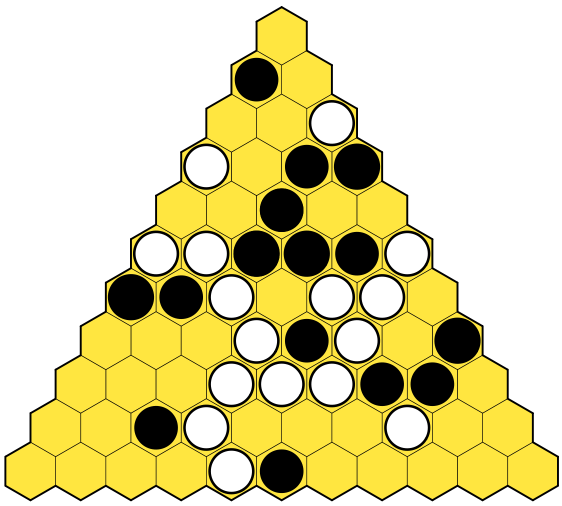

Figure 18. A game of Y won by White.

Y simplifies the Hex equipment by removing the need for the board edges to be coloured and for players to each have a defined direction (how many times have I confused which direction is mine in a game of Hex, upsetting my plans?). However, Hex is still the more strategically pure game, as players can focus on their single line of connection with considerable certainty, while the divergent connection threats in Y can soon get quite complex. Y could be described as clearer from a design perspective, while Hex is clearer from a strategic perspective.

5 Exploit the Geometry

This section describes ways in which the geometry of the equipment can be exploited, to implicitly enforce rules and help make games more mistake-proof, clear and elegant.

5.1 Deadlocks

It is no coincidence that the two connection games described above, Hex and Y, are played on a hexagonal basis. The hexagonal grid is *trivalent*, i.e. no more than three cells meet around any intersection, which allows the beautiful property that *exactly one player must make a winning connection*, and no game can ever be deadlocked for a tie. The board geometry itself avoids the need for an explicit tiebreaker rule, hence many connection games have a hexagonal – or at least trivalent – basis. See [1] for more details on this point.

By contrast, consider the hypothetical game shown in Figure 19, which is identical to Hex but played on a square (i.e. nontrivalent) grid. This example shows the white and black paths deadlocked around the central point, and this game cannot now be won by either player. In fact, neither player is ever likely to win this game, which is a huge disincentive to play it.

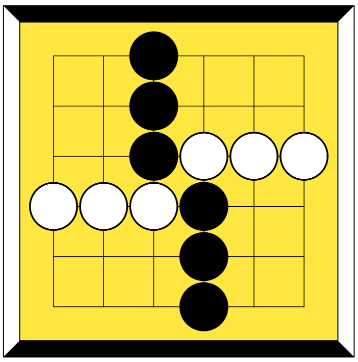

Figure 19. Deadlocked paths on the square grid.

Connection games designed for the square grid typically involve some mechanism to transcend the geometry and avoid such deadlocks. For example, the game Quax[14] avoids this problem by introducing an alternative move type, in which players can bridge across diagonally separated pieces, if such a move would not cross any existing bridge. Figure 20 shows a bridge that wins the game for White.

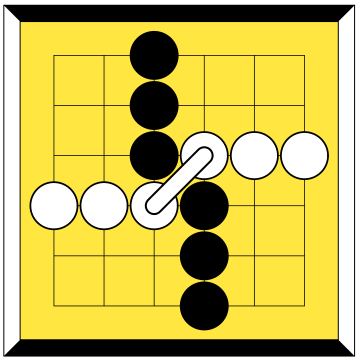

Figure 20. Resolving deadlocks in Quax.

This bridging mechanism solves the problem neatly, and allows some new and interesting strategies. Admittedly, it does introduce a new movement rule, but it is still *poka-yoke* in that it makes the game playable with as few rules as possible by exploiting the geometry.

The game Gonnect [14] provides another example of simplifying a rule set, while exploiting the geometry to solve a potential deadlock problem at the same time. Gonnect is a blend of Hex and Go, in which two players try to connect their sides of a square grid with a chain of their pieces, but also play with the surround capture, *ko*, and no-suicide rules from Go. However, it eliminates an important rule in Go, as players cannot pass.[15]

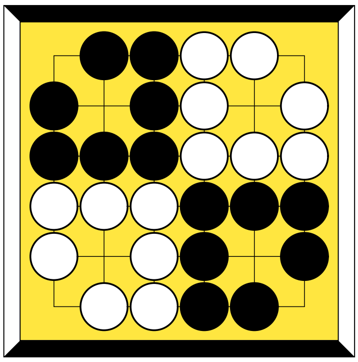

Figure 21. A cold Gonnect position.

To see the effect that this has on the game, consider the position shown in Figure 21. This position may appear to be heading for a stalemate,

[14] http://www.di.fc.ul.pt/~jpn/gv/quax.htm

[15] Often called the 'Gandalf rule' after his 'you cannot pass!' line in Tolkien's *Fellowship of the Ring*.

but it is not just *cold* – a term from combinatorial game theory meaning that the only moves available to the mover are disadvantageous – it is freezing, as the next player to move will lose.

Each of the four groups on the board have two *eyes* (internal holes) which in Go would make them safe from enemy intrusion, as the opponent cannot fill both holes to capture the group in the same move. But since passing is not allowed in Gonnect, and suicide moves are not allowed, the next player to move is forced to play in one of their own life-giving eyes, allowing the opponent to play in the other eye to capture that group next move and achieve a winning advantage. Removing the passing rule not only simplifies the rule set but elegantly resolves such temporary deadlocks.

5.2 Cycles

The *ko* rule from Go states that a player cannot repeat the board position from the previous turn, and is necessary to avoid loops of play. Figure 22 shows a classic *ko* situation, in which White captures a black piece, but Black cannot immediately recapture it back on the next turn. This rule could be described as a 'bug' that has become a 'feature' over the millennia, and entire volumes and schools of thought are now devoted to *ko* analysis.

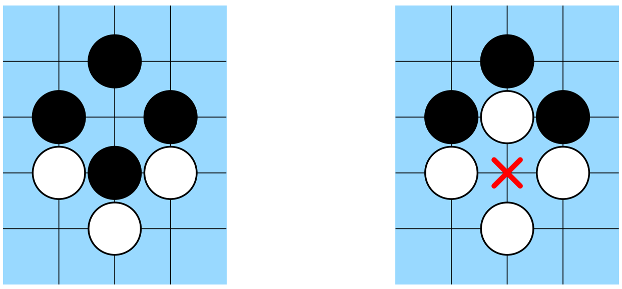

Figure 22. The *ko* rule: Black cannot recapture.

It was therefore a surprise when the computer program LUDI [15] produced the game Ndengrod,[16] in which two players compete to make a line of five of their pieces on a hexagonal grid, while using the surround capture and no-suicide rules from Go *but not the ko rule!* The game played well and did not suffer any problems with cycles, despite the lack of this apparently crucial rule.

Analysis soon revealed what was already known among Go researchers, that moving the surround capture mechanism from a square basis to a hexagonal basis removes the need for the *ko* rule. This is illustrated in Figure 23, where White has just captured a black piece with move *c*, but there is no danger of an immediate return capture and hence no need for *ko*. This is essentially due to the lack of diagonal connections in the hexagonal grid; see [16] for more details. LUDI had inadvertently chosen a geometry that avoided the problem of cycles, thus simplifying the rule set.

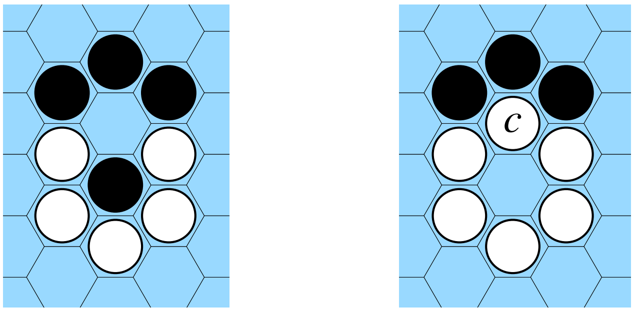

Figure 23. *Ko* is not needed on a hexagonal grid.

5.3 Stacking

The underlying geometry is obviously fundamental to games in which pieces stack on each other. The wrong choice of geometry here can cause serious problems that require additional rules to fix – if they can be fixed at all – while the right choice can produce elegant solutions with fewer rules. Consider the hypothetical marble stacking game, shown in Figures 24 and 25, in which White has laid a hexagonal platform of white marbles, upon which Black has stacked a single black marble.

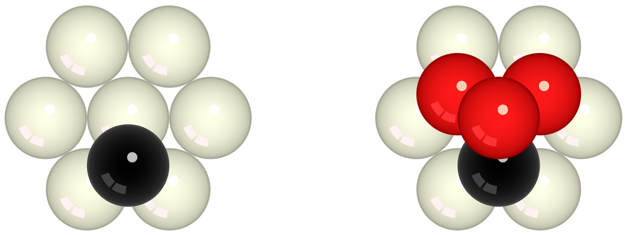

Figure 24. Stacking in phase I succeeds.

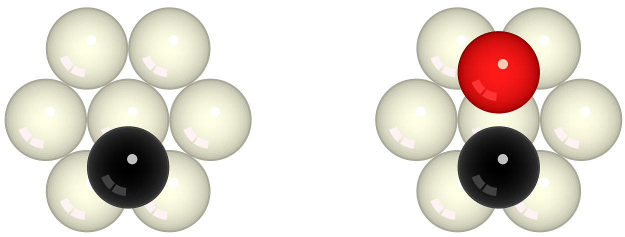

Figure 25. Phase II spoils the stacking.

In Figure 24, Red stacks two marbles adjacent to the black marble, then adds a further marble on top to achieve a *complete packing*. All marbles

[16]Later marketed as Pentalath: http://www.nestorgames.com/#pentalath_detail

in this example can be described as existing in the same *phase*, let's call it 'phase I'.

Figure 25 shows the other option available to Red, which is to stack a red marble across from the black marble so as not to touch it. In this case, the black marble is still in phase I, but the red marble is in phase II, ruining the packing as no further marbles can now be stacked in this example.

Mixing phases like this not only ruins the stacking, but can have serious implications for connection games played using this geometry. Games may become unwinnable due to the ease with which gaps can be created between groups of pieces, or games may become trivially winnable due to the ease with which potential blocking moves can be spoiled.

The designer can address this problem by introducing a rule that all marbles must be played in the same phase. But this solution is inelegant: it is hard to explain, hard to enforce, and error prone. It relies on players understanding the problem and correctly recognising the phase of each potential move, which is onerous and unrealistic for large board sizes; the players will spend most of their time just working out which moves are legal.

David Bush offers a more *poka-yoke* solution to this problem in his game Lazo [1]. This is a connection game played with pieces that stack within a hexagonal basis, which avoids the phase problem through the cleverly shaped pieces shown in Figure 26.

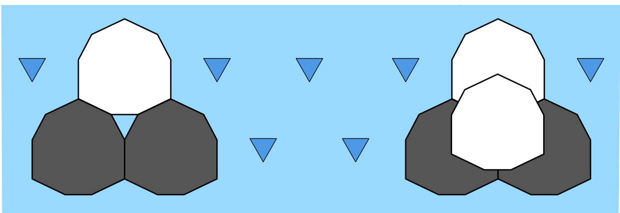

Figure 26. Lazo pieces force stacking orientation.

Each piece has a triangular peg on the bottom, which forces it to face in a particular direction when slotted into a board hole. Then whenever three adjacent pieces meet around a gap (Figure 26, left), that gap will also be triangular and facing in the same direction. Any piece that stacks is therefore forced to face in the same direction, due to its triangular peg, ensuring that all pieces remain in the same phase (Figure 26, right).

This is another example of exploiting the geometry to hide redundant rules and reduce player error. The inventor of Lazo has since reshaped the pieces to make the interstitial gap larger, so that players can see the colour of the piece underneath more easily, mistake-proofing the game even further through the equipment.

Another solution to the phase problem is to choose a different geometry altogether. For example, Figure 27 shows that marble stacking is not subject to such phase problems using a square basis. This is the reason that my own marble-stacking games, such as Akron [1], Margo [17] and the Shibumi set [18], all use a square basis.

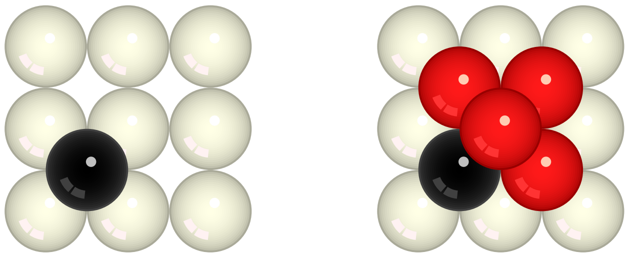

Figure 27. No phase problems in square stacking.

But what about the problem with deadlocks on the square grid, described in Section 5.1? It turns out that stacking games on the square grid transcend this problem, due to an unexpected emergent property.

Figure 28 (left) shows a graph in which the vertices are the centres of the visible marbles in a complete square packing, and the edges correspond to pairs of touching marbles. The dual of this graph (right) is trivalent, which is the necessary condition for deadlock-free connection;[17] a complete packing on this grid is guaranteed to produce a connection between opposite sides.

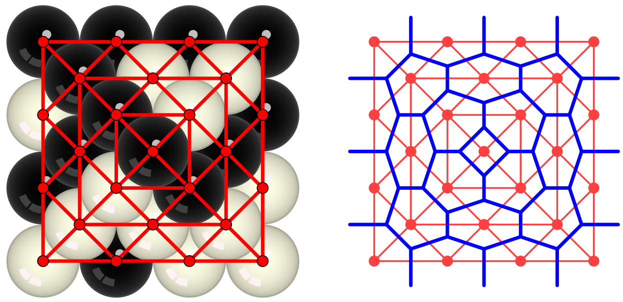

Figure 28. Guaranteed trivalent connection.

This fortuitous quirk of geometry makes the square basis suitable for marble packing connection games, such as Akron, without the need for additional deadlock avoidance rules. Further, Akron also has a drop mechanism, in which mar-

[17] Coincidentally, German designer Michail Antonow used an equivalent tiling to the dual shown in Figure 28 (right) for the board of his excellent connection game Conhex [1], although arrived at his design from a totally different approach.

bles can be removed under some circumstances to let higher supported marbles drop down. This is another case of exploiting the available geometry (and in this case gravity) to implicitly enforce physical rules that do not need to be stated to the player. The well known Connect Four [6] is another example of a game that exploits gravity to enforce a rule, namely dropping pieces to land on the highest empty slot of a chosen stack.

6 Conclusion

The examples above demonstrate the benefits of embedding the rules in the equipment of a game. Such benefits range from proofing against player mistakes (*poka-yoke*), to more subtle considerations such as design elegance, improving clarity, and tutorial assistance for players. This is certainly what I aim for in my own designs: *to move as much of the game into the equipment as possible*.

Assuming that it is generally good to embed the rules in the equipment, the question remains *which* part(s) of the equipment to move them into. For example, the game For the Crown [6] is a marriage of Chess and Dominion, with labelled pieces and cards that show relevant instructions and legal moves (as opposed to The Duke, in which the movement rules are inscribed on the pieces themselves). This separation of pieces from their relevant information makes it easy and cheap to replace the information cards, to allow new options and expansion packs for the game.[18]

This discussion has focused on abstract board games, and connection games in particular, as these are domains in which embedding the rules has obvious benefits. While I propose this as a general pattern for good game design, there will of course be exceptions: war games in which studying 100-page rule books is a necessary price of admission to the detailed simulation experience; narrative-based games in which added complexity enriches the atmosphere of the game for greater player immersion; and so on.

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[18]Observation by Nathan Morse, personal correspondence, 18 June 2015.

References

[1] Nystrom, R., *Game Programming Patterns*, New York, Geneva Benning, 2014.

[2] Browne, C., 'Elegance in Game Design', *IEEE Transactions of Computational Intelligence and AI in Games*, vol. 4, no. 3, 2012, pp. 229–240.

[3] Romeral Andrés, N., 'Heptalion', *Game & Puzzle Design*, vol. 1, no. 1, 2015, pp. 11–17.

[4] Nikkan Kogyo Shimbun Ltd., *Poka-Yoke: Improving Product Quality by Preventing Defects*, New York, Productivity Press, 1988.

[5] Freeman, J., *The Playboy Winner's Guide to Board Games*, New York, Playboy Press, 1979.

[6] Alden, S., *BoardGameGeek: Gaming Unplugged*, online database, 2000. https://www.boardgamegeek.com

[7] Bodlaender, H., *The Chess Variant Pages*, 1995. http://www.chessvariants.org

[8] Mott, P., 'Terrace: The Next Generation', *Los Angeles Times*, 16 September 1993.

[9] Hinch, D., *The Scrabble Book*, London, Pan, 1976.

[10] Leggett, T., *Shogi: Japan's Game of Strategy*, North Clarendon, Tuttle Publishing, 1993.

[11] *Fresh Slitherlink 3*, Tokyo, Nikoli, 2012.

[12] Spanier, E., *Algebraic Topology*, New York, McGraw-Hill, 1966.

[13] Browne, C., *Connection Games: Variations on a Theme*, Wellesley, AK Peters, 2005.

[14] Browne, C., 'Gonnect: The Best of Go and Hex', *Abstract Games Magazine*, vol. 1, no. 6, 2001, pp. 12–21.

[15] Browne, C., *Evolutionary Game Design*, Berlin, Springer, 2011.

[16] Browne, C., 'Go Without Ko on Hexagonal Grids', *ICGA Journal*, vol. 35, no. 1, 2012, pp. 37–40.

[17] Browne, C., *Margo Basics*, Raleigh, Lulu Press Inc., 2013.

[18] Browne, C. and Romeral Andrés, N., *Shibumi Rule Book*, Raleigh, Lulu Press Inc., 2012.

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