Orthogonal Analysis of StarCraft II for Game Balance

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ABSTRACT

Orthogonal differentiation is a suggested approach to game balance, but has never been formally tested. Using the game StarCraft II, a popular real time strategy game, we test whether game units are orthogonally differentiated. Units are considered vectors within an attribute space, thus calculating the rank shows whether orthogonal differentiation is consistent with the game. As we consider StarCraft II to be a balanced game, this will demonstrate whether orthogonal unit differentiation is necessary for game balance. This is not the case, with the StarCraft II units falling below the expected rank. We perform single value decomposition to better understand where the linear dependencies exist. While the result of the orthogonal differentiation test is negative, the orthogonal analysis poses useful insight into the game attributes.

Keywords

Orthogonal decomposition, balance, game analysis, StarCraft II.

1. INTRODUCTION

Game balance is a tuning process aimed at removing dominant strategies to give each player a chance of success. The process differs between games and while there are no standards, there are general guidelines to support it. One such guideline is the use of orthogonal differentiation[1], the mathematical process of differentiating vectors such that none can be reproduced through a linear combination of the any other in a set. In the context of games this means differentiating player choices such that each is unique, thus no combination of alternate choices will reproduce the same effect.

While the comparison to the mathematical definition of orthogonal differentiation is genuine, there is no evidence to suggest that it influences balance. Orthogonal unit differentiation was initially introduced as a guideline for better game design[10], then over time has been adopted as a guideline for balance[1]. While there is reason to believe that it could influence balance, no formal testing has taken place in the literature. This paper aims to fill that void by formally testing whether orthogonal differentiation is necessary for game balance. Also we investigate what insights orthogonal decomposition methods offer for game analysis.

To analyze its applicability, we test whether the popular game StarCraft II contains orthogonally differentiated units. StarCraft II is a Real Time Strategy (RTS) game, where players combat one another with armies for territories and resources, until one player is defeated. The game is under constant update to ensure balance for its large player base, thus is balanced enough for our purposes. As each unit is described by an equal number of attributes, then they can be represented as vectors. Therefore the StarCraft II data provides a test environment for orthogonal differentiation

Using the StarCraft II Heart of the Swarm unit attributes, we orthogonally differentiate the data using the Gram-Schmidt process, principal component analysis and single value decomposition.

1.1 StarCraft II

StarCraft II is a real time strategy (RTS) game, where players control armies in a science fiction setting. There are three unique armies: the Terran (humans), Protoss (advanced aliens) and the Zerg (alien monsters). Matches consist of between 2 to 8 players, where they compete either in teams or a free for all. Players collect resources, which they use to build structures, produce units and expand their base. The goal of the game is to defeat the enemy players by destroying all of their structures. Winning the game requires strategy, such as rushing the opponent with a small squad of units.

StarCraft II has maintained a large player base for years and is under regular balance update, due to this we make the assumption that the game is balanced enough. An unbalanced game is unsatisfying because the swing of power either makes the game frustratingly difficult, or boring. For a multiplayer game to remain popular, balance must be pursued through updates, otherwise players become dissatisfied and leave. This is is not to say that StarCraft II is perfectly balanced, indeed the continual balance updates imply otherwise. However, we consider the degree of imbalance to be inconsequentially minor.

1.2 Research Question

Is orthogonal differentiation necessary for game balance? If not, then which attributes in the space are underused? We

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Unit	Size	Cargo	Armor	Hitpoints	Attr.
Marine	0.75	1	0 (+1)	45 (+10)	L,B
Marauder	1.125	2	1 (+1)	125	A,B
Battlecruiser	2.5	-	3 (+1)	550	A,M,Ma

Table 1: StarCraft II Unit Attribute Sample

test whether orthogonal differentiation is used in a modern balanced competitive game, in particular the units of StarCraft II. To be clear, a lack of orthogonal differentiation does not mean an unbalanced game, but indicates that orthogonal differentiation is not a requirement.

For this paper we focus on unit attributes. There are other factors that effect game balance, such as map design. While we acknowledge other influences such as this, we consider each to be a separate balance research problem outside the scope of this paper. Instead we consider one small problem, which is the orthogonality of unit vectors and if there exists a connection to balance.

2. RELATED WORK

2.1 Definitions of Balance

There is no single definition of balance, thus we see a variety of interpretations. Game designers view balance as an aesthetic process that integrates game elements, such as map design, starting conditions and attributes to optimize for stability and enjoyment [7][8][5]. In this regard balance is a quality of the game design and thus harder to quantify. At its simplest, a balanced game is considered to be a game with no dominant strategies available [7][8][6]. Alternatively, difficulty adjustment is similar to balance, which can involve adjusting multiple distinct elements of a game [9, 7], including level design [9] and numeric attributes [7].

For this paper we use the simplest definition, that a balanced game is one with no dominant strategies. We consider balance to be property of the game itself and thus independent of player skill.

2.2 Orthogonal Differentiation for Game Design

Orthogonal differentiation for games was introduced in 2003, referred to as orthogonal unit differentiation [10]. The method aimed to differentiate game choices, in this case units in an army, such that no combination of any other choice would reproduce the same effect. This was suggested purely as a means of adding meaningful variety, with no mention of balance being a consideration.

Since then orthogonal unit differentiation has been suggested for balance application, with the requirement of a victory condition that involves a combination of strategies[1]. The core notion is that diversity of unique strategies is less likely to produce a single dominant strategy. If the game requires a combination of strategies to succeed, then there's less chance of a single dominant strategy if each is orthogonally differentiated.

3. VECTOR REPRESENTATION OF STARCRAFT II DATA

Games use numeric attributes to define choices, but to test orthogonal differentiation we require them in vector format. Furthermore, we need to test a balanced game to search for a connection to orthogonal differentiation. We have chosen to use StarCraft II as our balanced test environment. We use unit data from StarCraft II Heart of the Swarm downloaded from http://wiki.teamliquid.net/starcraft2/Protoss_Unit_Statistics. In the case of StarCraft II, we have a mix of numeric attributes, functions and string based categorization, as seen in table 1. In order to convert this mix into a consistent vector format, we need to follow a particular process described below.

All attributes need to be converted to a single numeric value, but without discarding data. Categorization attributes such as "Attr." are represented as either a single letter, or a pair of letters. To convert these to a vector representation we need to split each category into a new attribute and represent the unit membership as a value of 0 or 1. In effect, we convert these categorizations into boolean values as different attributes. Attributes with functional descriptions such as "Armor" need to be split into a new attribute for each variable.

After this conversion there are 65 attributes in the StarCraft II data. Each attribute forms a dimension in our vector space, leaving us with a 65 dimensional space. Each is converted into a set of vectors and then represented as matrix.

4. ORTHOGONAL DECOMPOSITION METHODS

The rank of our matrix will inform us whether the StarCraft II data is orthogonally differentiated. However, to gain better insight we plan to use multiple methods of orthogonal decomposition to determine the rank.

4.1 Gram-Schmidt Process

Given a set of vectors in matrix notation A, where each row in $A = \{a_1, a_2, ...a_n\}$, the Gram-Schmidt process [4] produces a set $E = \{e_1, e_2, \dots e_n\}$ of orthogonal unit vectors. The process proceeds iteratively, starting with $e_1 = \frac{a_1}{\|a_1\|}$ and calculates the subsequent $e_i = \frac{u_i}{\|u_i\|}$, where $u_i = a_i - \sum_{j=1}^{i-1} proj_{u_j} a_i$, by removing components parallel to any preceding vectors.

Each e_i is orthogonal to the subspace spanned by $e_1, \dots, e_{i-1}$ and hence provides a vector that distinguishes unit i from the previous $i-1$ units. There are some issues anticipated in using this form of analysis, in particular the process is sensitive to the order in which the vectors are processed.

This serves as the most basic method of orthogonal differentiation.

4.2 Principal Component Analysis

Principal component analysis (PCA) is used for statistical analysis, commonly to realign a set of data points to a new basis that describes the variance in the data. This is useful where data trends are not immediately apparent such as in high dimensional data. However we are purely interested in the orthogonal basis vectors it produces.

Given the set of vectors A we determine the covariance matrix C, where we find the eigen values α and eigen vectors λ. PCA [2] finds a set of orthogonal basis vectors ordered from most variance to least. Unlike Gram-Schmidt the original order of vectors has no influence on the basis vectors determined by PCA.

Primarily PCA serves as a canonical point of comparison in this paper.

4.3 Single Value Decomposition

Single value decomposition (SVD) takes a rectangular $m \times n$ matrix, which in this case is the set of StarCraft II vectors A in transposed matrix notation. A^T is decomposed into $A^T = USV^T$. Where $U \in \mathbb{R}^{m \times n}$ contains columns of eigen vectors for AA^T and $V^T \in \mathbb{R}^{m \times n}$ contains columns of eigen vectors for $A^T A$[3]. The eigen vectors of U and V^T each form an orthonormal basis for the matrix A^T based on its rows and columns respectively, S is a diagonal matrix of square rooted eigen values of U and V^T. Because we are interested in finding which attributes go unused, we use the orthonormal basis U, which describes an orthonormal basis of the rows of A^T. Because of the transpose, the rows correspond to attributes.

SVD decomposes the set into eigen vectors based on rows and columns, which correspond to units and attributes respectively. Because the eigen vectors described are based on a square matrix derived from $A^T A$, then the elements of each eigen vector correspond to the original attributes.

In particular we are curious about the null space of U^T, which should provide insight into which vectors are underused.

5. RESULTS

5.1 Initial Analysis

An initial analysis of the data shows that there 69 units in StarCraft II, but only 65 dimensions once reformatted as vectors. This automatically discredits orthogonality being a requirement for game balance. Considering this fact, we are now interested whether the StarCraft II matrix rank is below 65, as this would indicate that not all attributes combinations are used.

5.2 Rank and Orthogonal Differentiation

The results of the Gram-Schmidt process indicate a consistent rank of 56, which is below the expected amount of 65.

Single Value Decomposition

The Gram-Schmidt process provides us with insight into the rank, but frankly not much more than that. Both Gram-Schmidt and PCA can rebase the vector data, but as it is based on unique attribute quantities, rebasing them creates a new set of attributes comprised of combinations from the original set. While this is an intriguing concept, it sheds no light on which unit vectors are being underused. To answer this we need to trace the linearly dependent vectors back to the original attribute description. As a result of this rebasing, it is impossible to tell which attributes from the original set contribute to the rank, as the vectors have been transformed beyond recognition.

To investigate which vectors are being underused we utilize SVD. As single value decomposition returns eigen vectors based on a decomposed square row and column matrix from the original, it maintains the existing set and order of units (rows) and attributes (columns). We use the transposed data matrix A^T, so the rows are aligned to attributes

	1	2	3	4	5	6	7	8	9
Bonus base	1	1						1	
Bonus add			1	1	1	1	1		1
Bonus B base							1		
BonusB add									1
Bonus L base	1	1						1	
Bonus L add	1	1						1	
Bonus Ma base	1		1			1			
Bonus Ma add	1			1	1		1		1
Bonus Air base									
Bonus Air add			1	1	1	1	1		1
Bonus Shield add	1	1		1		1		1	
Bonus S base			1		1		1		1
Bonus S add		1				1	1	1	
Bonus DPS base			1	1	1	1	1		1
Bonus DPS bonus	1	1						1	
Bonus DPS L base	1		1	1	1	1	1		1
Bonus DPS L bonus		1						1	
Bonus DPS Air base		1		1	1		1	1	
Bonus DPS Air bonus	1	1				1	1	1	1
Bonus DPS Ma base		1	1	1			1		1
Bonus DPS Ma bonus	1			1	1		1	1	
Bonus DPS B base	1	1	1	1	1	1	1	1	
Bonus DPS B bonus		1	1		1	1			1

(attribute names listed on the left, and the 9 null space vectors they belong to listed to the right)

Table 2: Null Space Vectors

instead. We can then analyze the null space of the eigen vectors produced by using SVD on the StarCraft II data. The null space should then indicate which vectors are underused.

The results of the SVD test are shown in table 2. The null space analysis of the SVD decomposition produced 9 null space vectors, which is exactly what we would expect given the rank. Table 2 indicates which attributes are non zero for each null space vector . The attributes are varieties of bonus attributes, used to specify a contextual advantage over an opponent. For example a unit with the attribute "Bonus Air base" will deliver extra damage to units of air type.

6. ANALYSIS

While there are many potential units that could be created within the attribute space of StarCraft II, the game design limits what attribute combinations form useful units. For example, a unit must start with more than 0 hitpoints, otherwise the unit will be considered dead on spawn and thus be destroyed immediately. So while it is possible to define a unit composed of 0 hitpoints on paper, it would be unintuitive for game use. Similarly, most units would require some combination of speed and damage to be useful.

For this reason, the null space vectors describe useless in game units, as none of them have base attributes. Furthermore bonus attributes build off base damage attributes, in effect adding advantageous bonus points to damage in a specific context. To clarify further discussion, we make the following definition.

Reliance - An attribute has a game design dependency on another.

We specifically distinguish this definition from linear dependence, as they are not equivalent. If the bonus attributes were linearly dependent then we would expect the rank to be 42, as there are 23 bonus attributes listed in table 2. As the rank is 56, this implies that the bonus attributes are not linearly dependent.

Each bonus attribute described in table 2 is reliant, in that they provide a contextual addition to another attribute. This implies that they do not work well in isolation and would be counter intuitive to the game design. Reliant attributes are not unique to StarCraft II, thus the consistency of null space vectors provides a reliable method for determining unused vectors and implying reliant attributes in other games.

This adequately explains why the null space vectors are unexplored in the StarCraft II data, the lower matrix rank implies that not all vectors form useful game units.

7. CONCLUSION

We assume that StarCraft II is balanced due to it's consistent player base and updates, however it cannot be orthogonally differentiated. This affirms that orthogonal differentiation is not necessary for game balance, but says nothing on whether it could be sufficient.

The secondary research question was if there were a break in orthogonality, could we determine what attributes were underused. A null space analysis of SVD eigen vectors answered this question, showing that vectors composed entirely of reliant attributes comprised the unused portion of the attribute space.

This however raises interesting questions regarding mathematical representations and analysis of games. For example, in this case analyzing the null space presented us with useless attribute combinations. However, this is entirely a product of the mathematical representation of the game. If the game were represented in a way that removed reliant attributes such as bonus attributes, then the null space could indicate viable attribute combinations, which due to their linear independence would describe undiscovered unique roles in game. This could help designers scan their own game space for new potential units. Thus a space without reliant attributes would increase the value of SVD for game designers.

Furthermore, a space without reliant attributes would provide increased value to orthogonal differentiation, in particular procedural unit generation. Given an attribute space, a set of orthogonal unit vectors could be generated, which would each provide unique in game roles.

PCA could also provide insight, as the eigen vectors produce an orthogonal basis from the variation within the space. This potentially gives some interesting analysis into where this variation exists in a game.

This all depends on whether a game space can be represented without reliant attributes, which is possible. For example, as all units require hitpoints to serve an in game purpose, then the space could be rebased such that there exists a subset of basis vectors that all contain a portion of hitpoints. Thus, any unit vector created within the subspace would already meet the base requirement of hitpoints. The same concept could be applied to any of the reliant attributes.

There is broad application to any game that can represent in game choices as vectors. Representing game choices mathematically without reliant attributes opens the door to valuable analytic insights and procedural choice generation. Applying orthogonal decomposition methods to the StarCraft II data shows no connection between StarCraft II balance and orthogonal differentiation, illustrating that it is not necessary for balance.

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