Geometric Analysis of Maps in Real-Time Strategy Games: Measuring Map Quality in a Competitive Setting

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Abstract

Professional competitive gaming has grown increasingly lucrative over the past 2 years since the release of *Blizzard Entertainment*'s real-time strategy game, *StarCraft II: Wings of Liberty* (SC2). Since there is no widely used SC2 map generator, most maps are hand-crafted by level designers who may not be in touch with the game's intricate and shifting strategy, resulting in inconsistent game quality. Here we develop a tool that algorithmically identifies a map's key geometric elements and analyzes them to judge if a map is of good quality. Our quantitative approach simplifies the question of whether the map is worthy of being used in a competitive setting, and reduces reliance on human judgments of quality.

1   Introduction

The ideal competitive multiplayer game must satisfy a number of conditions. In particular, such a game should be highly technical in nature, roughly balanced, and interesting to watch for spectators as well. The satisfaction of these conditions has grown in importance, since fairly large sums of money are now at stake in some competitive games, such as StarCraft II (SC2).

There are two competitive outlets for SC2: one is the official unprofitable ladder, directly accessible to anyone who owns a legitimate copy of the game, and the other is through organized profitable tournaments. These tournaments have been growing in size, with some reaching over 180,000 concurrent online viewers, and individual tournaments having prize pools of over $180,000 USD [1].

Games on the ladder are played on random maps from a pool that changes occasionally and is managed by Blizzard, while tournament map pools can include user-designed custom maps, made in the free official SC2 map editor. The selection of maps to include in these pools has been an important and difficult problem in SC2's history so far: professional players generally reject new maps included in tournament pools because these pools are inconsistent throughout unaffiliated tournaments, and it is often inconvenient to practice on maps dependent on a single tournament. Players generally reject new maps in the ladder pool because Blizzard is notorious for designing strategically unsound and uninteresting maps. A simple solution to these problems would be for Blizzard to design good ladder maps, which players can practice on for some time, and later on introducing these maps in tournament map pools. This effort, however, depends on map designers being able to accurately and consistently measure map quality, an effort that requires deep knowledge of game-play.

Our approach here is to develop a set of metrics and accompanying toolset that quantifies map quality. We build our design on years of experience in competitive SC2 gaming, developing a set of heuristics that we feel correlates with better game experiences. These heuristics are expressed and formalized as a set of geometric properties, which can then be calculated for a given map. This is an entirely static design, aiming at producing approximate but nevertheless reasonably reliable values independent of individual player style. We validate our metrics by comparison with a few maps chosen for their generally recognized good and bad game-play, as discussed on SC2 forums and as recognized by competitive organizations.

Specific contributions of this work include:

- We identify a set of relevant geometric properties of SC2 maps that intuitively correlate with properties known to be present in SC2 maps that have good qualities.

- We develop a tool that computes a set of metric values based on our geometric properties from a given SC2 map.

- Using the computed data, we provide basic heuristics to measure map quality, and demonstrate application and value of this approach on a few well known SC2 maps.

In the next section, we detail some of the background knowledge required to understand our motivations and the game of SC2. Then, we present some of the related work done in spatial partitioning and analysis. Afterwards, we present the problem definition, including key intuitive properties relevant to map quality. This is followed by a description of some of the attempts at identifying important map properties. Finally, we discuss extensions of these properties, possible improvements, applications, and future work on related topics.

2 Background

SC2 is a real time strategy game (RTS) in which the player competes against others to ultimately achieve world domination. The player selects a race of creatures with which to build bases (expansions), gather minerals and gas, construct buildings, develop an economy, train an army by spending gathered resources, and eventually defeat his opponent who is trying to do the same. The order and choice of expansions made by a player is called his expansion pattern, and is typically carefully chosen so that each base is readily defendable. Defense is usually established by placing defensive units and buildings that have a fixed radial attack range, covering areas of interest.

There are 3 available races: the Terran, Protoss, and Zerg. Each differs from the others in fundamental ways. However, the races are designed with balance in mind at the competitive level, i.e. the high level winning rates are expected to tend towards 50% for all race matchups. In practice, this has been a reliable and accurate measure of the state of SC2's balance.

The game can be played in several team formats or against an AI, but the competitive scene is nearly completely focused on the 1vs1 format, where one human player faces off against a human enemy. The game is won when a player surrenders, or when all of his buildings are destroyed.

3 Related Work

A central concern in analysing RTS game-play is understanding the nature of the underlying terrain or map. Map features can constrain expansion, modify resource availability and game pace, and are one of the fundamental properties that vary between game-plays. This begins with basic space partitioning, to determine the main regions of interest and their connectivity. Perkins, for instance, has developed a highly successful spatial partitioning tool named the *Broodwar Terrain Analyzer* (BWTA) [9] for use with *StarCraft: Brood War* (BW), SC2's predecessor. This tool partitions a map's walkable terrain into regions and their associated choke points. Regions are defined as connected walkable polygonal areas that do not contain choke points. Choke points are defined as corridors that link regions together and that, when walled off, would either merge two distinct unwalkable obstacles into one, or disconnect two previously connected walkable regions. The partitioning algorithm relies on several heuristics which are set to produce output that most closely resembles a player's intuitive strategic identification of regions and choke points.

Some work has been done in the analysis of RTS game maps in a refined 2D grid. In particular, the *SC2 Map Analyzer* [4] provides some spatial analysis and a graphical way to determine positional imbalance, i.e. whether or not a map is asymmetrically fair. However, these grids are impractical for strategic analysis due to the strategic importance of regions and choke points themselves.

Our work thus builds on top of the basic spatial partitioning structure provided by BWTA. Given this coarse map representation of polygonal regions and choke points, we are able to apply non-trivial analysis using network analysis and computational geometry tools.

4 Problem Definition

Our intent is to ascertain map quality as a property distinct from map balance: balance in map design is largely ensured through approximate symmetrical placement of obstacles, resources, and base locations.

We first assume that all units in the game are perfectly balanced, i.e. on an ideal map, there are no possible race-specific exploits that highly benefit a player of a certain race. In addition, we assume that balance and quality are being considered in a 1vs1 high level competitive setting. Finally, we assume some trivially verifiable map necessities, such as the presence of an equal distribution of resources per base per player, etc.

Map quality itself depends more on the opportunities presented to a player based on resource allocation and terrain structure. Player behaviours are strongly constrained by the potential *expansion pattern*, or sequence of bases each player acquires during gameplay. Bases which are highly accessible to both players imply conflict, while bases that are more individually accessible allow players to build infrastructure for defense and future offense. Within this, gameplay becomes most interesting at an optimal balance between potential conflict and ability to acquire resources: conflict too early in the game results in short gameplay where players are only able to exploit a subset of game units and the outcome largely depends on luck and success in racing toward the other player, while conflict that is overly postponed results in long games with each player well entrenched, requiring excessively long sieges for one player to win. As rough ideals, each player should be able to expand 3 times before conflict becomes inevitable, with base position and shape requiring defensive costs scaled by their relative order of acquisition. These overall heuristics guide our observations on what kinds of maps produce the best gameplay:

- "One-dimensional" maps tend to induce games that feature similar strategies or tactics which eventually become overused. This is a complex property which can have several causes. One of the more important of these causes is a conflicting set of expansion patterns due to badly tuned region contention.

  Such a situation is prominently featured in the SC2 ladder map *Jungle Basin* (see Figure 1(a)). In this example, a player's standard third base choice is highly contended: two short paths link each player's third base through the center of the map.

- Another important cause is the presence of a disproportionately defendable region of importance in the map. Whether an area in a map is too defendable or not defendable enough, it consistently becomes the focal point of the games played thereon.

  This is an issue present in the map *Incineration Zone* (see Figure 1(b)). Here, the player's first base and third bases may be intuitively described as disproportionately wide, granting enemy access from several points of entry and thus requiring excessive resources devoted to defensive structures. In addition, the second base is disproportionately small and easily accessible to the enemy, inspiring early conflict.

- Some rare maps feature unusual geometric terrain structure, such as "thin" base regions or assailable area. This particular structure usually results in several difficulties, such as defensive problems due to maneuverability and mobility issues.

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(a) Jungle Basin   (b) Incineration Zone   (c) Kulas Ravine
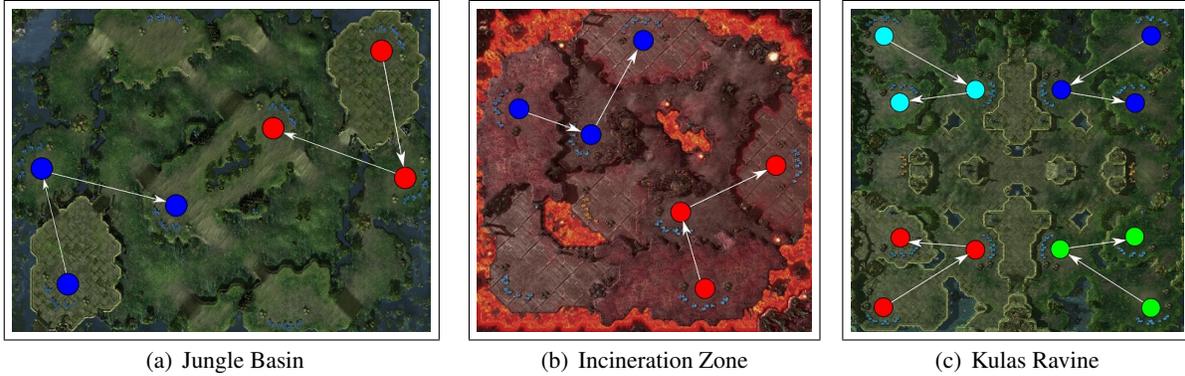
Figure 1: Exploitable game states and maps. The directed graph overlays indicate base locations and typical player expansion patterns.

This is present in the ladder map *Kulas Ravine* (see Figure 1(c)). On this map, the structure of thin regions creates several long, narrow, and windy paths between all locations, making it difficult to maneuver around enemy forces, and making it easy to form an imposing presence with long range siege units.
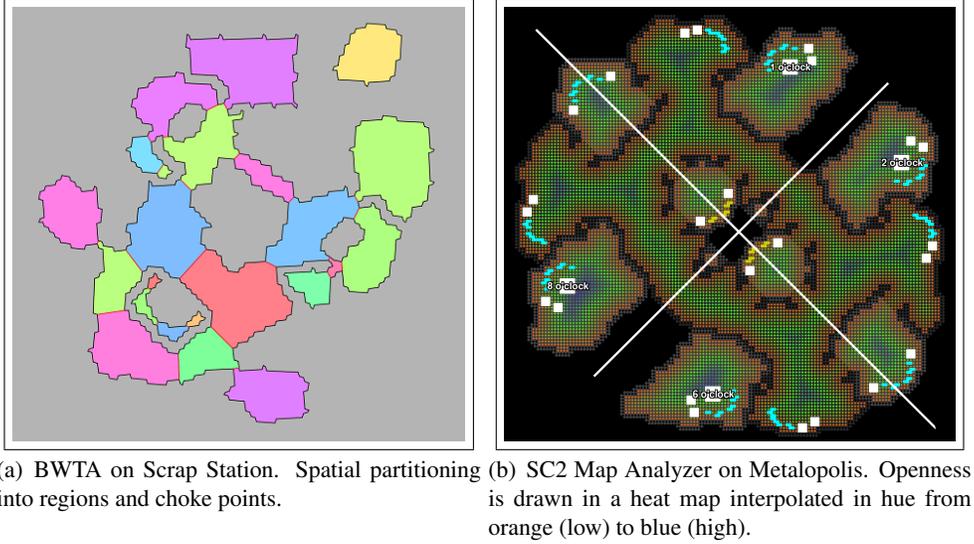
- Although we do not directly address balance in this work, it is an important aspect of map quality, and one that may also be related to the geometric properties we discuss in the next few sections. To be balanced in any sense, maps should be nearly rotationally or reflection symmetric. Most maps do not perfectly obey this, and slightly deviate due to the restrictions of a square cell-based map structure, or simply for aesthetic reasons. Maps that are not sufficiently symmetric, however, such as *Scrap Station*, suffer from minor balance issues. As can be seen in Figure 2(a), although the map has an approximate reflective symmetry, strategically important *choke points* are not equally allocated, giving a slight bias to the player starting in the bottom right.

5 Analysis

Our approach to measuring a map's quality amounts to formally identifying measures of individual map properties which give primitive information about quality. A weighted combination of these individual measures then gives a rough idea of a map's overall quality. In this section, we describe measures which identify quality in the examples provided above by quantifying some of the important principles of terrain structure as they relate to expansion patterns and region defendability.

Since BW and SC2 feature geometrically similar maps, we use Perkins' approach in BWTA to partition SC2 maps into regions and choke points, as they are defined in his tool. More specifically, the algorithm finds these regions by making use of the Computational Geometry Algorithms Library (CGAL) [2] as follows.

1. Compute the segment Voronoi diagram of polygonal obstacle line segments in a map. This work was developed by Karavelas and is beyond the scope of this paper [8].

2. Heuristically prune the diagram to remove edges which do not represent an important part of the map's structure.

3. Identify region and choke point nodes in the diagram.

(a) BWTA on Scrap Station. Spatial partitioning into regions and choke points.

(b) SC2 Map Analyzer on Metalopolis. Openness is drawn in a heat map interpolated in hue from orange (low) to blue (high).

Figure 2: Example output from related algorithms.

4. Heuristically merge adjacent region nodes.

5. Determine the polygonal shape of a region by walling off each choke point.

The result of this process is an abstract, graphical representation of the map where nodes represent closed polygonal regions, and edges model their connections (choke points); an example is shown in Figure 2(a). Given this basic decomposition, we next extrapolate several geometric measures and structures relevant to identifying the undesirable game state properties shown in the problem definition. These are based on formalized concepts of *openness, centrality, accessibility, control,* and *coverage.*

5.1 Openness

The SC2 Map Analyzer defines the *openness* of a cell as the shortest Euclidean distance from that cell to any unwalkable cell. Drawing this measure using a heat map allows for a helpful visualization of how open and maneuverable a cluster of cells is in a map (see Figure 2(b)).

We extend this concept to regions as a means of measuring the shape of a region, in relation to how easy a region is to defend or attack—long, thin regions reduce maneuverability within the region, and result in large perimeters for defense. Given a region r, we thus define the openness $O(r)$ as:

$$O(r) = w(V(r))$$

where $V(r)$ is the point set of vertices of r, and $w(S)$ is the width of the convex polygon conv(S), i.e. the shortest distance between two parallel lines of support for the point set S [10].

5.2 Centrality

Player progress and movement within SC2 maps is largely regulated by the connectivity of regions—the majority of units in SC2 are ground-based, and must traverse only walkable terrain. Regions that act as

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movement "hubs" thus have a strong strategic importance in the game, and are often the source of conflict or contention. In a graph or network context, this property is defined through various notions of node *centrality*.

Let a map be partitioned into a graph $G = (V, E)$, with regions V, choke points E, and extended distance metric d_G. The *degree centrality* of a region $r \in V$ is the number of choke points incident upon it:

$$\mathbf{C}_d(r) = \deg(r)$$

In the context of network analysis, a node with higher degree has a higher ability to rely on adjacent nodes and to use a network's resources [7]. In addition, it is more likely to be a third-party for some information flowing through the network. Analogously, a region with high degree can be reached more easily from adjacent regions and is likely to be part of a path in a tactical engagement. In our environment this may signify that such a region is important in the control of resources.

Degree centrality, however, is a purely local property that does not consider the importance of choke points in terms of which regions they facilitate access to. A more global alternative to degree centrality is *betweenness centrality,* which is defined as follows:

$$\mathbf{C}_b(r) = \sum_{s \neq t \neq r} \frac{\sigma_{st}(r)}{\sigma_{st}}$$

where $\sigma_{st}(r)$ denotes the number of shortest paths from s to t passing through r, and σ_{st} is the number of shortest paths from s to t. Similarly to degree centrality, the more central a node is, the more likely it is to be part of some exchange of information.

Other potential centrality measures are *closeness* and *farness centrality*. Closeness is a measure of how easily a node can communicate with others in the network. Formally:

$$\mathbf{C}_c(r) = \sum_{v \in V} d_G(r, v)$$
$$\mathbf{C}_f(r) = \frac{1}{\mathbf{C}_c(r)}$$

Tactically, closeness is again a measure of contention: the more easily a node can communicate with others, the more likely it will at some point. Farness is simply defined as the inverse of closeness, and so can be seen to measure reduced potential for contention.

Figure 3 gives a comparison of these centrality measures. We favour farness in our analysis because it encodes information about connectivity and virtual distances, while the other two presented measures only consider connectivity. It should however be noted that betweenness and farness are interchangeable, in some cases.

5.3 Accessibility

An important part of map quality is determined by a player's access to regions. The ability to obtain (and retain) control of a region constrains expansion patterns, and guides overall strategy with respect to offensive or defense approaches.

We use a novel graph-theoretical measure to approximate the concept of region *accessibility*. Let $P = (p_1, p_2, \ldots, p_n)$ be a player's game state, describing the set of regions acquired by the player in acquisition

| (a) Degree centrality | (b) Betweenness centrality | (c) Farness centrality |
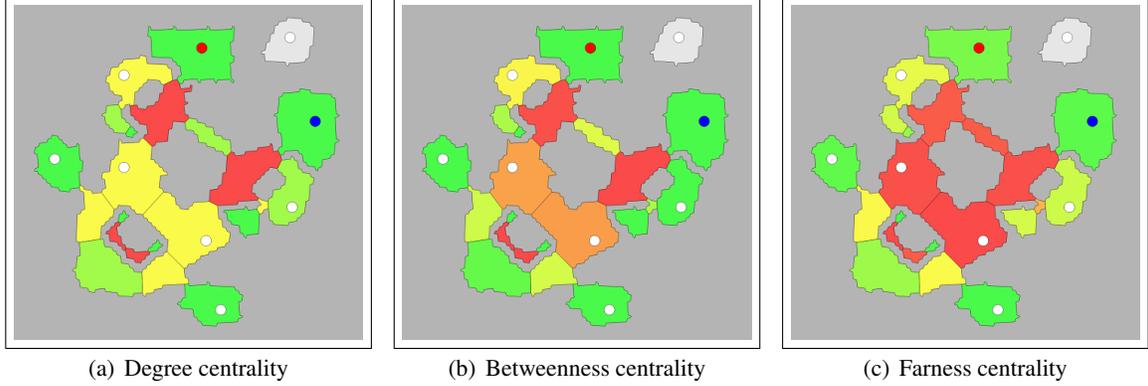
Figure 3: Centrality measures interpolated in hue from green ($C(r) = 0$) to red ($C(r) = 1$).

order. Let $\mathbf{w} \in (\overline{\mathbb{R}}_+)^n$ be defined as follows:

$$\mathbf{w} = \begin{bmatrix} d_G(p_1, r)^{-1} \\ d_G(p_2, r)^{-1} \\ \dots \\ d_G(p_n, r)^{-1} \end{bmatrix}$$

with $0^{-1} := \infty$. We will obtain a measure of accessibility as a function of this vector. Consider the relevance of a norm's axiomatic properties when applied to such a vector in the context of SC2:

1. $\|\alpha\mathbf{v}\| = |\alpha|\|\mathbf{v}\|$: accessibility is directly proportional to how close the player's bases are to $\mathbf{v}$.

2. $\|\mathbf{v}\| = 0 \iff \mathbf{v} = \mathbf{0}$: a region is only completely inaccessible if it is completely inaccessible from all captured bases.

3. $\|\mathbf{u} + \mathbf{v}\| \leq \|\mathbf{u}\| + \|\mathbf{v}\|$: a region is more accessible to a base set than it is to individual bases.

Then, we know that a correct accessibility measure in this case must be a norm. Consider the p-norm for $1 \leq p \leq \infty$, where:

$$\|\mathbf{w}\|_p = \left(\sum_{i=1}^n d_G(p_i, r)^{-p} \right)^{1/p} \quad \text{for } p < \infty, \text{ and}$$

$$\|\mathbf{w}\|_\infty = \max_{1 \leq i \leq n} \{d_G(p_i, r)^{-1}\}$$

Hence, the higher the p value, the more important an individual base becomes in calculating accessibility (see Figure 4).

5.4 Controlled area

Control or dominance of a game region is typically defined using a Voronoi diagram, resulting in a graph where locations closer to one player are controlled by that player. Such an approach in SC2 is less appealing for a variety of reasons: map traversal limitations require the more complex constraint-based Voronoi diagram, different units have different movement speeds and thus different definitions of proximity, and perhaps
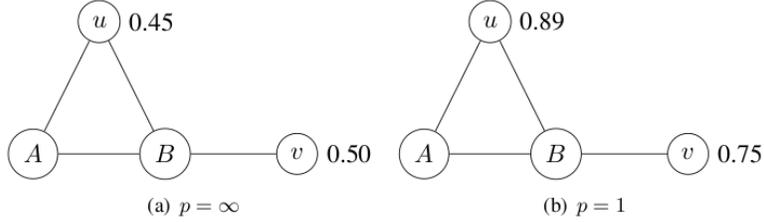
Figure 4: Accessibility measured with differing p values. Bases A and B are taken by the player. Note that the expansion patterns differ.

most importantly a good Voronoi representation would require knowing actual unit placement, something not available with any precision from an ahead-of-time consideration of a static map.

We thus base our notion of controlled area on the very coarse-grained representation of expansion patterns, and base ownership. In SC2 a player directly controls a region by owning the base allocated to that region, and so the union of such regions gives a well-defined measure of player dominance. Unfortunately, this fails to take into account regions that do not contain bases, as well as regions that have disproportionate accessibility to one player, and so should be interpreted as controlled even if not actually owned.

Another simple model for determining the area that a player controls is through the use of the convex hull. Given the player's game state $P = (p_1, p_2, \ldots, p_n)$, we say a region r is controlled by the player if:

$$C(r) \in \text{conv} \left(\bigcup_{i=1}^{n} V(p_i) \right)$$

with $C(r)$ being the centroid of r. Again, this has significant limitations; in particular, regions which are linked to other player-controlled regions only through paths that contain an enemy-controlled region may nevertheless be counted as player-controlled. It is usually up to interpretation as to whether or not these should be valid judgments, but regions obeying only these conditions usually are not seen to satisfy strong enough conditions to be controlled by either player.

Trivial use of the convex hull would thus seem to be overly generous, while the polygonal union of all controlled region polygons is overly precise. The α-*shape* effectively provides a solution to this problem by a parametrization that interpolates between the above two approaches. The α-shape is a generalization of the convex hull that specializes into an intuitive and malleable idea of shape formed by a finite point set. When $\alpha = 0$, the α-shape of some point set is its convex hull. When $\alpha < 0$, the polygons formed from edges in the α-shape allow some concavity. Thus, finding the best representation for a player's controlled area would amount to finding an appropriate value for α.

Given the base set of controlled regions (owned bases) $Q = \{q_1, q_2, \ldots, q_m\}$ and optimal $\alpha = \alpha_c$, where c is the number of connected components in Q, we define the player's controlled area as:

$$\mathcal{C}_{\alpha_c} \left(\bigcup_{i=1}^{m} V'(q_i) \right)$$

where $V'(q_i)$ is the point set of vertices of the q_i in addition to some distribution of Steiner points, $\mathcal{C}_\alpha(S)$ denotes the α-shape of S (see Figure 5). The optimal value α_c is chosen so that it is the smallest α value for which all data points are either on the boundary or in the interior of the resulting α-shape A, and that A has at most c components. The implementation is largely based on the work of Edelsbrunner [5].

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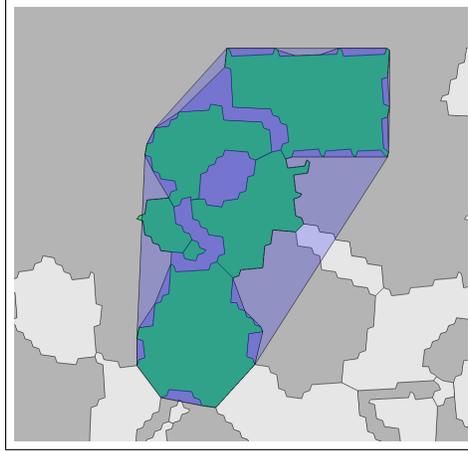
Figure 5: Light blue is the convex hull of player-owned base regions; regions with player owned bases are green; dark blue is the optimal α-shape of player controlled area.

5.5 Covering

In SC2, defendability of a region is provided largely by units with powerful and long-ranged attack capability. Computing defendability cost of a region is thus a matter of determining the coverability of a region by the (circular) ranges of such defensive units.

Covering problems, however, are difficult to solve and could add sizable practical complexity to this calculation. As minimization problems, computing covering values may also entail more precision than is required for this analysis. Of course, we could instead employ a Monte Carlo algorithm to approximate a covering problem solution for point, contour, and area coverage and easily find relevant information. To ensure agreement in assessing map quality, however, we seek fully deterministic solutions.

Contextually, it is unnecessary for a player to cover his entire controlled area with defensive units. Usually, it suffices to cover important choke points and important contours of the player's controlled area. The former placements provide defense against ground units, while the latter defend against potential air attack. This reduces the problem to largely one of covering region contour, albeit with the need to still consider potential overlap in thinner areas of a region. We thus use the *straight skeleton,* a topological skeleton developed by Aichholzer [3]. To compute coverage we shrink a player's controlled area by using the area's interior straight skeleton, taking the complement of that polygon restricted to the controlled area. This yields the important contour strip desired. Here, using α-shape becomes important.

6 Experimental Analysis

Given the geometric measures and structures defined in the previous section, we revisit the game states described in the problem definition, and attempt to make judgments on map quality.

6.1 Contention Order

The general player and viewer opinion on contention is that each player's (first and) second base should not be contended, while subsequent bases should rapidly grow in potential contention. Note that immediate base

(a) Jungle Basin   (b) Metalopolis
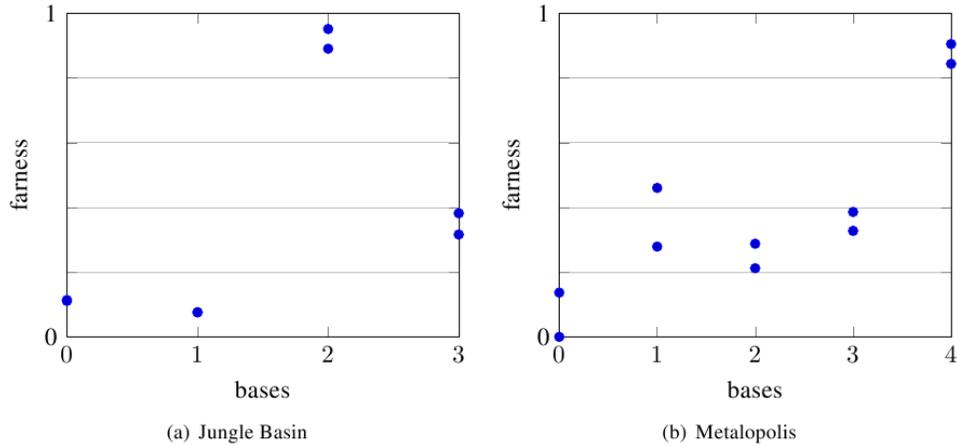
Figure 6: Farness as contention. The two points show contention measurements based on the most likely expansion pattern for each player. We observe the undesirable peak in contention at the third base on Jungle Basin.

contention might be measured in terms of conflicting accessibility: if a player's base is highly accessible to the enemy, given some game state, then it is contended at that point in time. To measure contention, however, we mainly rely on farness (closeness) centrality. As a global concept, this measure should contain information about contention at an eventual point in the game.

Farness measurements suggest that an ideal distribution exists in terms of base region centrality. Maps which deviate too much from this distribution tend to be "one-dimensional," resulting in premature contention that limits opportunities for deep strategization. This can be seen in the two example maps shown in Figure 6. Metalopolis is known as a high quality map, demonstrating low contention for the first three bases, and very high contention for the fourth. In comparison, Jungle Basin, well known as a poor map, shows very high contention early on, at base 2. In this case players are brought to conflict prior to being able to build interesting defensive or offensive strategies, and without being able to make use of the more varied and complex units available later in gameplay.

6.2 Defendability

The region contour determination developed using the straight skeleton of a player's controlled area is directly relevant to the player's air vulnerabilities. A contour strip of greater area requires a larger amount of resources to defend effectively, either literally through the purchase and placement of defensive units, or mechanically through the tactical management of contours that are worth defending. Either way, there is a relationship between a player's contour strip area, the enemy's ability to reach that area, and some measure of how defendable the player's controlled area is. In particular, in terms of measuring map quality, it is clear that the presence of a disproportionately defendable or indefendable contended region negatively affects gameplay. The former produces long, tedious siege sequences and potential stalemates, while the latter provide little value for players to seek out or attempt to control.

Our defendability measure is thus based on the area of the contour strip. As above, we propose that there is an ideal distribution of region defendability for all regions in a map, at all game states. This can be seen by comparing the computation for maps anecdotally known to be either good or bad in tournament play, as shown in Figure 7. Metalopolis, a good map, shows a smooth spread of contour areas, mostly bounded near
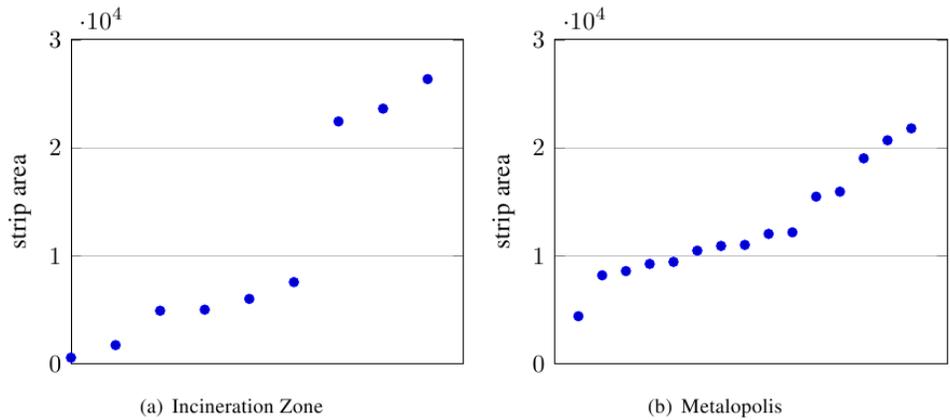
Figure 7: Contour strip area for game regions. Observe the large jump in strip area for Incineration Zone.

the middle of our contour area range. Incineration Zone, however, demonstrates a much wider variance, with regions largely polarized as either overly defendable or excessively vulnerable.
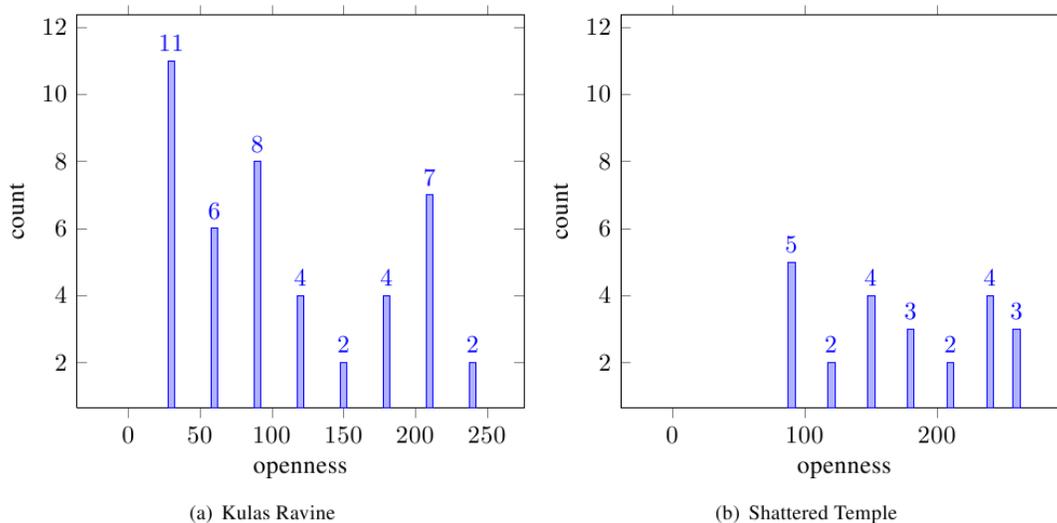
6.3 Openness

Openness relates to map quality in a few ways, and can also be used to separate map quality in relation to the difference SC2 races. A map with too many "thin" regions, for example, gives an unfair advantage to Terran players, who have easy access to siege units that can damage a large area. On the other hand, if there are too many open regions, the map might be better for Zerg players, whose units are generally more effective in open controlled areas. A quality map, however, should allow for even matching of the different races, reflecting the intended game balance and maximizing variety in competitive play.

We compare the undesirable openness properties of the Kulas Ravine map to the more ideally structured Shattered Temple map. Results are shown in Figure 8; both maps are of similar size, and so should have roughly similar counts and distribution of openness values. Kulas Ravine, however, has not only many more regions, but also many more thin regions than Shattered Temple. This illustrates Kulas Ravine's known advantage to Terrain players, and suggests a quantitative way of determining whether choice of race is being overly constrained by the fundamental structure of map terrains.

7 Conclusion & Future Work

Our intention in this work is to modularize the verification of map quality and make the process of determining and ensuring map quality more accessible to less mechanically skilled designers. This effort has culminated in a tool which provides algorithmic spatial partitioning of SC2 maps. We formally identify and apply several key geometric properties and measures used to reason about SC2 map quality, and show their relevance through their correlation with real game and map states.

Of course while our experimental work is encouraging, it is also clearly preliminary, based on evaluating a few, known and well polarized examples. Our immediate future work is aimed at more thorough verification, building a library of maps anecdotally known to be good or bad in player opinion, and examining our calculations in a more statistically rigorous fashion to ensure our calculations agree with any established

Figure 8: A histogram of openness in maps. Note that bars are computed based on a bin width of 30.

human consensus.

A larger body of evaluation data would also allow us to investigate variations or refinements of some of our geometric properties. We have seen how betweenness centrality can be a relevant measure of the importance or contention of a region. In particular, betweenness considers the importance of a region in the set of all geodesics in the map. However, in the context of SC2, it is not always relevant to only consider geodesics. For instance, a region may have several paths of entry which are linked to the same adjacent region, in which case each of these paths would be worthy of consideration. Freeman's flow betweenness centrality, which relies on the concept of network flow, considers the contributions of all simple paths in a graph, and might give a more relevant and complete measure of betweenness in SC2 [6].

In addition, though α-shapes certainly appear to be a correct representation of the concept of a player's controlled area, the choice of inserted Steiner point distribution remains uncertain, nontrivial, and important. We expect that a uniform distribution is sufficient to produce good results, but the question of point density still remains.

Greater accuracy may also be achieved by a deeper consideration of SC2 mechanics and features. A number of particular gameplay mechanics, for instance, have been ignored in this analysis: the influence of high-yield mineral bases and bases with unusual resource distributions, the presence of destructible rocks which temporarily obstruct building and passage, the consideration of Xel'Naga towers, which are neutral units that provide a large vision radius to a player when a player-owned unit is within close proximity to a tower, etc.. In addition, we have yet to explore the measurement and judgment of several more complex undesirable game states, usually involving more particular interactions between specific races.

8 Acknowledgments

References

[1] Liquipedia.   Website.   `http://wiki.teamliquid.net/starcraft2/Premier_Tournaments`. Last visited Aug. 10 2012.

[2] CGAL, Computational Geometry Algorithms Library. Website. `http://www.cgal.org/`. Last visited Aug. 23 2012.

[3] O. Aichholzer, F. Aurenhammer, D. Alberts, and B. Grtner. A novel type of skeleton for polygons. *Journal of Universal Computer Science*, 1(12):752–761, dec 1995.

[4] dimfish.   SC2 Map Analyzer.   Website. `http://www.sc2mapster.com/assets/sc2-map-analyzer/`, 2010. Last visited Aug. 2 2012.

[5] H. Edelsbrunner. Weighted Alpha Shapes. Technical Report UIUCDCS-R-92-1760, Department of Computer Science, University of Illinois, Urbana-Champaign, Illinois, U.S.A., 1992.

[6] L. C. Freeman, S. P. Borgatti, and D. R. White. Centrality in valued graphs: A measure of betweenness based on network flow. *Social Networks*, 13(2):141 – 154, 1991.

[7] R. A. Hanneman and M. Riddle. Introduction to social network methods. Online book. `http://faculty.ucr.edu/~hanneman/nettext/`, 2005.

[8] M. I. Karavelas. A robust and efficient implementation for the segment voronoi diagram. In *Proc. 1st Int. Symp. on Voronoi Diagrams in Science and Engineering*, pages 51–62, 2004.

[9] L. Perkins. Terrain analysis in real-time strategy games: An integrated approach to choke point detection and region decomposition. In G. M. Youngblood and V. Bulitko, editors, *AIIDE*, pages 168 – 173. The AAAI Press, 2010.

[10] H. Pirzadeh. Computational Geometry with the Rotating Calipers. Master's thesis, McGill University, 1999.