2016 International Conference on Collaboration Technologies and Systems

Abstract Argumentations Using Voronoi Diagrams

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***Abstract*— This work introduces a novel approach to dynamic online machine to machine argumentation, which does not require human intervention. The proposed model is a hybrid between weighted, Dung style argumentation frameworks, and competitive facility placement Voronoi games and delivers the outcome in graphic form.**

Keywords—abstract machine to machine argumentation; multi-agent systems; Voronoi game;

I. Introduction

Argumentation is the process in which agents exchange and evaluate interacting and inevitably conflicting arguments. It is a form of dialog during which beliefs, understanding and opinions are presented, explained, compared, and defended. The arguments are the basis for inferences, negotiations, conflict resolution, and conclusions drawn by logical reasoning.

Argumentation is one of the oldest research foci and one of the most enduring ones in Artificial Intelligence [6], [21] and in parallel in Philosophy, first in [24] and most recently in [20]. Abstract argumentation has been a rich and varied new discipline that started with [7] and widely credited to [13]. It has been adapted to many domains including computational law [11] and multi-agent negotiations [14]. The most vigorous and prolific argumentation research has been conducted with Argugrid (www.argugrid.eu) [23], which is a grid based research consortium funded by the European Union and directed by Dr. Francesca Toni of Imperial College in London, United Kingdom.

A. *Abstract Argumentation*

Dung style argumentation is a well-known model for the abstract argumentation process [13]. An argumentation framework consists of a set of abstract interacting arguments lacking internal structure or specific interpretation, a set of attacks (i.e., contradictions) between them, and semantics for evaluating these arguments. Dung's framework prescribes a set of arguments A and a binary attack relation R among them. This binary relation is often denoted as $\rightarrow$ between a pair of arguments. Pollock's inference graphs [20] are very similar to graphs produced by depicting Dung's attack relationships. For brevity, listed here are only the main properties for set A without elaborate notations and detailed explanations that needlessly obscure the essence of discussion [13].

1) Subset A' is an acceptable set with respect to a set of A of arguments. Every argument in A' is defendable against an attack. This is assured by having arguments in the set complement A – A' protect arguments in A' by attacking possible offending arguments. This is a rather common phenomenon in society. This is how in-groups emerge [19]. An in-group holds steadfast to a set of arguments it finds acceptable and repels others.

2) Subset A' is conflict-free. There are no attack relations among any pairs of arguments in A'. This is less common than the acceptability property but in-groups exhibit this phenomenon as well.

3) Subset A' is admissible. Once A' is conflict free, if A' is acceptable, then every argument in A' must be acceptable with respect to A. Finally,

4) Subset A' is a stable extension of A. Once A' is conflict free, it is a stable extension if and only if it attacks every argument in the complement set A – A'. This property appears to identify a xenophobic tendency that is an unreasonable fear or hatred of the unfamiliar. As such, this notion of stability might appear rather an odd fit for a scientific endeavor.[1]

Equivalently, the argumentation frameworks are represented using binary graphs in which the nodes are arguments and the edges are attacks among them. The edges of the graph are directed arcs indicating that one argument attacks an incident node. Dung formally defines the admissibility of arguments as one of three possible absolute statuses – accepted, rejected, and undecided. A single attack on an argument is sufficient to automatically retract it [13]. In most cases however, arguments are not equally strong so this approach does not migrate well. Usually, an argument will at least weaken a conflicting argument but will not necessarily negate it completely. Extensions of Dung's setup have been created to tackle the lack of levels of relative strength and acceptability of arguments outside of the support/attack relations and accepted/rejected/undecided status. Relaxing attacks delivers a more refined way to analyze conflicting information. These extensions are Weighted argumentation frameworks.

Consider the following arguments:

[1] This notion is traced to the long standing Arab-Israeli conflict example elaborated in [8]. This may account for this bizarre characterization. A similar example is Hatfield-McCoy feud (1878 – 1891), the account of American folklore that has become a metaphor for bitterly feuding rival parties in general.

978-1-5090-2300-4/16 $31.00 © 2016 IEEE

DOI 10.1109/CTS.2016.87

- a_1 = The vehicle is fuel efficient, practical, and affordable, we should purchase it.
- a_2 = Our current vehicle is in good condition and the estimated maintenance costs are below the added cost of the new vehicle, we should not purchase it.
- a_3 = The warranty on our current vehicle is about to expire, we should purchase the new vehicle.

The first two arguments are mutually attacking but clearly have different weights. Argument a_3 weakens argument a_2 but is not sufficient to destroy it entirely. By attacking a_2, a_3 defends the first argument. In order to address the lack of relativity, it is prudent to augment arguments with weights. A ranking-based framework modeled after Dung introduces acceptability ranks for arguments, which can be compared. These rank-order arguments can vary by degree of acceptability and there are an arbitrarily large number of these degrees. Rankings depend only on the attacks between arguments and not on the identity of the arguments themselves. An argument can be attacked multiple times by other arguments and is no longer removed, only downgraded in acceptability – the higher the rank of the attacking argument, the greater the downgrade. Defenders of arguments – attacking their attackers – have the opposite effect on the degree of acceptability. In this approach, the set of semantics transforms the argumentation graph of the framework into a ranking on its set of arguments: from the most accepted to the weakest. Further refinement is the ability to, depending on the decision-making situation and context, give dominance to the cardinality or quality of attackers [4], [5]. A game-theoretic approach to argument weights models the argumentation framework as a repeated two-person zero-sum game. Recursive computation and the minimax theorem determine the strength of an argument by taking into accounts its attackers and defenders [17], [18]. In a weighted argumentation framework on the other hand, weights are not attached to the arguments, but to the attack relations between them. The weight of an attack relation is a positive real number, representing its relative strength. This shift from argument weights to attack weights allows conflicting arguments to coexist. The addition of an inconsistency budget metric adds flexibility to the level of tolerance of attacks with total weight below a certain threshold [12]. Attack weights can also be used to derive defense, acting as a de-facto preference relation [9].

B. Voronoi Game

As stated, sophisticated argumentation models profit from the ability to simultaneously attach weights to both arguments and attack relations. A game-theoretical approach lends itself well to multi-player argumentation – both cooperative, and adversarial. Furthermore, the Voronoi diagram (i.e., Voronoi game) is a geometrical construct that can be employed as a visual aid to help observe the continual struggle among a group to gain the upper hand in argumentation. Voronoi has been applied in many other domains to model competition among a group such as mobile robot mapping and sensor network coverage. Here the participants are argumentation nodes and the arena is a space representing a virtual space of arguments over a single issue. A Voronoi game is a geometric model for competitive facility location. Two players place sites in a virtual argumentation arena and capture parts of it. The resulting partitioning is a Voronoi tessellation of the play area into regions called Voronoi cells [10], [25]. Using the nearest-neighbor rule, each point belonging to the cell is closer to the cell's site than to any other site specific to another region. The goal is to place the sites in a way that results in the capture of as much of the play area as possible.

A Voronoi game can be played on different arenas, in different dimensions, as continuous or discrete, and as a one round or a multi-round game. In the general case, the two players – A and B – take turns placing n site points on a bounded continuous arena. On a 1-dimensional continuous domain, where the play area is a circle, the second player has the advantage, but the first player controls its degree, so the game is effectively a tie [2]. When continuity is no longer present and the game is played on a line segment, player A has the winning strategy [3]. If the Voronoi game is altered to a one-round game on a 2-dimensional bounded playing field, player A places all sites in a symmetric play area without holes and then player B places his sites in full knowledge of the positions player A already occupies. The Voronoi cells are constructed using Euclidean distance and the player controlling more area is the winner. In these circumstances player B is guaranteed the existence of a winning strategy. Even though player A in this setup is always at a disadvantage and is guaranteed to lose, he can keep the winning margin to a minimum [8]. If the arena is not symmetric, there are configurations of rectangular play area aspect ratio and number of sites in which player A is guaranteed a win with a fixed margin. If the area is a polygon with holes, deciding whether in the one-round game player B can capture more area over a certain winning margin is an NP-hard problem [15]. In a one-round vindictive Voronoi game [1], player B can utilize his knowledge of player A sites' Delaunay triangulation to insert a minimum subset of his site points in a way that minimizes the neighborship between player A sites. In a one-round maximum neighbor Voronoi game the winning approach is to acquire more neighbors than the opponent [22]. In these isolation games, the second player either wins or ties the game and can effectively avoid self-interference better than his opponent.

There is no known optimal strategy for the original multi-round Voronoi game for dimensions higher than one, where players take turns placing sites on the playing field.

The game, of course, does not necessarily need to be contentions. The ability to form coalitions between players and unify playing strategies to capture the most combined area remains. Cooperative facility location is a well-studied operations research problem.

II. THE VORONOI ARGUMENTATION GAME MODEL

A Voronoi diagram can model numerous phenomena (cell structure, lava textures, growth of crystals, road networks, territorial behavior of animals, marketing, etc.) and find various uses (search for nearest neighbor or closest pair of points, base station placement problem, image compression, data segmentation, finite difference methods, distribution of resources, path planning for search and rescue robots, evacuation modeling, surveillance, sensor networks, etc.). The Voronoi game is a natural intuitive game, albeit difficult to analyze in the general case. One possible and until now unexplored application of the game is the modeling of weighted extensions of the Dung-style argumentation framework.

In this novel approach the competitive argumentation game will result in a Voronoi tessellation as shown in Fig. 1 and 2. The argument topic is modeled as a unit area 2-dimensional bounded region. Arguments are represented by circles around a point (site) on the plane. Overlapping segments of different circles denote conflict between arguments, which is resolved by dividing the overlapping area as shown in Fig. 3. The points within an overlapping portion are absorbed by the region whose site the point is closest to, using Euclidean distance. Another distance metric can be applied where appropriate but using the Euclidean Distance ensures that the line segment, which is the border between two sites, is exactly midway between them. An arbitrary number of players take turns selecting and bringing forth an argument from the framework in the form of a spatial position. Because this is a multi-player multi-round game, the intuitive strategy is greedy – the selection of the next argument aims to maximize the total area captured by the player at every round.

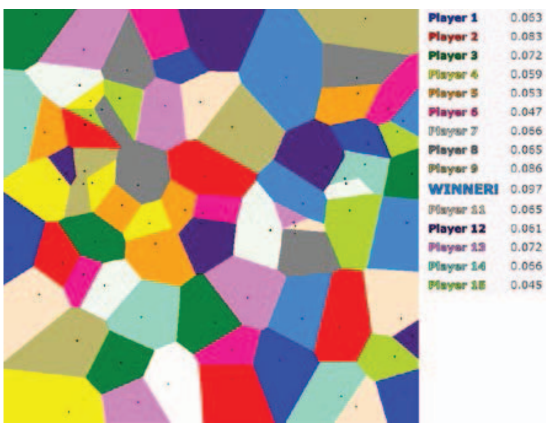

Figure 1. Example Voronoi tessellation after an argumentation game with 15 players in 5 rounds where attacks are of equal strength

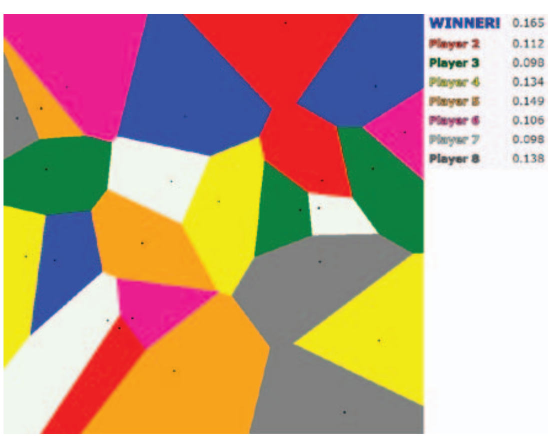

Figure 2. Example Voronoi tessellation after an argumentation game with 8 players in 3 rounds. The winner is Player 1 who claimed 16.5% of the arena

This setup offers the opportunity to extend Dung's original model by weighting the attack relations. The spatial position of the center of the argument circle determines the arguments it attacks. The proximity between the attacking argument's site and the site of the opposing arguments will establish the strength of attack. If all arguments in the framework have the same weight, the radii of the circles representing them are equal and large enough for a single argument, if advanced first, to claim the entire play area as demonstrated in Fig. 3.

The arena can thus be covered by two arguments as well as it could be covered by a number of them, so the entire available utility in the form of captured area is claimed at every round of the game. In addition to ascribing strength to the attack relations between arguments, the arguments themselves can also be weighted. Assigning each site a radius to reflect the argument strength, as shown in Fig. 4, adds another level of refinement to the model. By having knowledge of both argument and attack strength, a player can make an informed selection at each round that will help him acquire the most utility with the least amount of self-interference.

Modeled like this, Voronoi cells can represent an abstract argumentation framework and, more specifically, its results. The argumentation game is a weighed extension of Dung's original framework and provides the option to assign relative strength to both arguments and attacks between them. We created an algorithm to animate the model. Its current iteration assumes that all arguments have equal weight. Adding argument weight is a planned improvement. The algorithm delivers the step-by-step Voronoi tessellation resulting from each move made by a player. The playing field is currently rectangular and has fixed dimensions, other arena shapes and arenas with holes are a potential extension. The spatial coordinates of the arguments are generated at random or provided as input parameters. Before the game starts all of the arguments are potential moves.

Each player chooses the best argument at each round. The best argument is selected from the list of potential moves and allows the player to capture the most possible total area – the new area resulting from placement of the new argument plus the area he already owned at the beginning of the round. For simplicity, and in order to not duplicate the game moves given the same list of arguments and number of players, the algorithm starts by assigning the first player a random argument from the list. The first argument always claims the entire arena but in truth that puts the player at a temporary disadvantage, especially if the site of that argument is close to the edge. The selection of an argument with a site as close to the center of the argumentation arena as possible would keep the size of the area taken away by the next player to a minimum. Such an argument however, has other drawbacks in the long run, as it will almost definitely be surrounded by other sites as the game advances, losing its initial benefit. As the argumentation game progresses through multiple rounds and more sites are placed in the arena, the first move advantage of a centrally positioned argument or the disadvantage of an argument with a site closer to the edge diminishes or disappears since the strategy of all players is greedy. Thus, player one is not precluded from winning, as the outcome of the game depends largely on the arguments in the framework and their proximity (i.e., strength of attacks) to other arguments.

Since the output is graphic, the most intuitive way to represent the play area is with a pixel grid. The Voronoi tessellation itself is created by looking at every pixel in the grid in turn. The Euclidean distance between the pixel and all sites in the arena is computed. The pixel is absorbed into the cell (receives the color of the cell) controlled by the closest site. Each pixel in control of a player receives that player's color. For all following moves the corresponding player traverses the list of remaining arguments, temporarily creates their tessellations and computes the resulting normalized utility – the number of pixels captured divided by the total number of pixels in the arena. For accuracy, since argument sites can never be captured, they are excluded from the utility calculation, so the total number of pixels in play changes with each move. The player whose turn it is then selects the argument that delivers the most utility, places is in the arena, claims the area by coloring it in his color, and takes the argument out of the list of possible moves.

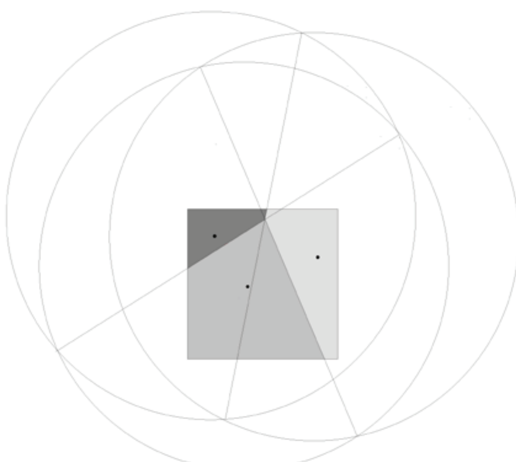

Figure 3. Formation of Voronoi tessellation for three arguments of uniform weight

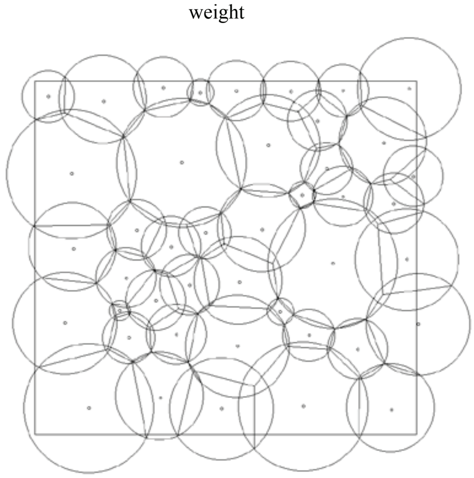

Figure 4. Formation of Voronoi tessellation for multiple arguments of variable weight

Algorithm 1 Voronoi Argumentation Game

Require: *dimx; dimy*: dimensions of argumentation field
  n: number of players
  a: number of arguments per player
  $< x; y >$: list of pairs of spatial coordinates to represent arguments, length of the list is $n * a$
Ensure: visual representation of the normalized utility
  obtained by each player after a rounds
  Declare the player controlling most of the area as the winner

  Create empty playing filed with dimensions *dimx; dimy*
  Designate a distinctive color for each player c_i
  if no moves yet **then**
    $player_1$ chooses argument $< x_i; y_i >$ at random
    move argument from argument list into arena
    claim one unit of utility for $player_1$ {no opponents}
  end if
  for all other moves **do** {choose best move for $player_i$}
    for all arguments remaining in argument list **do**
      temporarily create Voronoi tessellation and compute corresponding utility
    end for
    find argument resulting in maximum utility for $player_i$
    move that argument from argument list into arena
    update utility u_i for all players
  end for
declare winner as the player with the most utility *ui*

function: voronoi
for all points in the arena **do**
  compute Euclidean distance from point to all sites in arena
  assign color of closest site to point
end for

After all arguments have been placed in the arena, the game is over and the maximum total number of captured pixels in a certain color determines the winner.

The coordinate space of the game arena represents a subspace of relative argument comparison. Argument site coordinates are a mathematical abstraction in order to facilitate the comparison between arguments and do not carry an immediate real-world meaning such as the argument dimensions or strengths of arguments. Thus, an argumentation framework is transformed into a Voronoi argumentation game for a mere visual presentation.

For the vehicle purchasing example from above, the argumentation framework with sample weights ascribed to the attacks relations is shown in Figure 5. Since the metric of choice to determine the area gained by an argument is the Euclidean distance, when mutually attacking arguments are present in the system, the argument attacking with greater strength will prevail. The new weight of the attack relation of that argument becomes the difference between its original weight and the weight of the lesser relation. The weaker relation is destroyed.

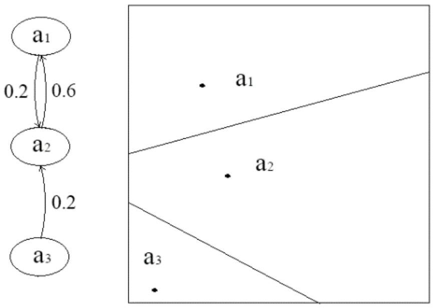

Figure 5. Example weighted argumentation framework and its Voronoi argumentation game tessellation

In the example presented in Fig. 5, the remaining attack relation is $a_2 \rightarrow a_1$ with updated weight of 0.4. Then, nominal weights can be appropriately normalized to suit the arena. Attack relation weights are inversely proportional to the distance between argument sites. Arguments a_1 and a_2 are closer to each other than a_2 and a_3 because they are in greater conflict. The proximity between sites is what directly affects the area gained by an attacking argument.

In complex frameworks, players must select one of multiple arguments to use as their next move. The best arguments selection procedure for large numbers of players and/or arguments places a considerable computational burden on the algorithm. One possible optimization is using Fortune's algorithm [16] in the Voronoi function. This efficient algorithm uses a sweep line to compute the tessellation in O(nlogn) time. Even with this improvement, in a Voronoi argumentation game with many players or many arguments, while the number of arguments is still high, selection of the best move for every player still presents an optimization challenge. Since this work's focus is not the algorithm but the model, computational complexity concerns and possible solutions are left out.

The Voronoi argumentation game can be applied to different scenarios. It is a model for multi-agent argumentation with the added flexibility of weighted argumentation frameworks and the advantage that it allows to assign varying weights to both arguments and attacks. The game can be adversarial or can permit the formation of coalitions. The Euclidian distance metric can be replaced with a metric more appropriate for the desired application; the arena can be re-shaped to reflect an argumentation topic. The pictorial representation is not only a helpful visualization tool to track the argumentation progress but it also allows agents to compute their next best argument to bring forward. The Voronoi argumentation game is a versatile novel approach to abstract multi-agent argumentation.

III. CONCLUSION

We introduced rubrics of machine to machine argumentation to facilitate dynamic, online argument synthesis without human intervention. It is the authors' belief that this will augment multi-agent computing in useful ways. We presented a novel Voronoi game setting, which provides a way to ascribe weight to both arguments and attacks, as well as visualize the results and determine a winner in an abstract argumentation framework.

REFERENCES

[1] S. I. Ahmed, M. Hasan and A. Sopan, "Vindictive Voronoi games and stabbing Delaunay circles," in International Symposium on Voronoi Diagrams in Science and Engineering (ISVD), 2010, pp. 124–131.

[2] H.K. Ahn, S.W. Cheng, O. Cheong, M. Golin and R. van Ostrum, "Competitive facility location: the Voronoi game", Theoretical Computer Science, vol. 310, 2004, pp. 457–467.

[3] H.K. Ahn, S.W. Cheng, O. Cheong, M. Golin and R. van Ostrum, "Competitive facility location along a highway," in 7th Annual International Computing and Combinatorics Conference LNCS, vol. 2108, 2001, pp. 237–246.

[4] L. Amgoud and J. Ben-Naim, "Argumentation-based ranking logics," in Proceedings of the 2015 International Conference on Autonomous Agents and Multiagent Systems (AAMAS '15), 2015, pp. 1511–1519.

[5] L. Amgoud and J. Ben-Naim, "Ranking-based semantics for argumentation frameworks," in Proceedings of the 7th International Conference on Scalable Uncertainty Management, (SUM '13), 2013, pp. 134–147.

[6] T.J.M. Bench-Capon and P.E. Dunne, "Argumentation in artificial intelligence," Artificial Intelligence, vol. 171(10-15), 2007, pp. 619–641.

[7] L. Birnbaum, "Argument molecules: A functional representation of argument structures," 1982.

[8] O. Cheong, S. Har-Peled, N. Linial, and J. Matoušek, "The one-round Voronoi game," in Proceedings of the eighteenth annual symposium on Computational geometry (SCG '02), ACM, New York, NY, USA, 2002, pp. 97–101.

[9] S. Coste-Marquis, S. Konieczny, P. Marquis and M.A. Ouali, "Weighted attacks in argumentation frameworks," in Proceedings of the 13th International Conference on Principles in Knowledge Representation and Reasoning (KR'12), 2012, pp. 593–597.

[10] L. Dirichlet, "Über die reduction der positiven quadratischen Formen mit drei unbestimmten ganzen Zahlen," J. Reine u. Angew, Math. 40 (1850), pp. 209–227.

[11] P. E. Dunne, "Prevarication in dispute protocols," in G. Sartor, editor, Proceedings of the 9th International Conference on AI and Law (ICAIL), New York, NY, USA, ACM Press, 2003.

[12] P.E. Dunne, A. Hunter, P. McBurney, S. Parsons, and M. Wooldridge, "Weighted argument systems: Basic definitions, algorithms, and complexity results," Artificial Intelligence, vol. 175(2), 2011, pp. 457–486

[13] P.M. Dung, "On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games," Artificial Intelligence, vol. 77(2), 1995, pp. 321–358.

[14] S. Fatima, M. J. Wooldridge and N. R. Jennings, "An agenda based framework for multi-issues negotiation," Artificial Intelligence Journal, 152(1), 2004, pp. 1–45.

[15] S.P. Fekete and H. Meijer, "The one-round Voronoi game replayed," in 8th International Workshop (WADS'03), vol. 2748, 2003, pp. 150–161.

[16] S. Fortune, "A sweepline algorithm for Voronoi diagrams," in Proceedings of the second annual symposium on Computational geometry, 1986, pp. 313–322.

[17] P.A. Matt and F. Toni, "A game-theoretic perspective on the notion of argument strength in abstract argumentation," 11th European Conference on Logics in Artificial Intelligence, Springer, 2008.

[18] P. Matt and F. Toni, "A game-theoretic measure of argument strength for abstract argumentation," in Proceedings of 11th European Conference on Logics in Artificial Intelligence (JELIA'08), in LNAI, vol. 5293, Springer, 2008, pp. 285–297.

[19] D.C. Pennington, The social psychology of behavior in small groups, Psychology Press, 2002.

[20] J. Pollock, "Defeasible reasoning and degrees of justification," in Argument & Computation, Taylor and Francis, 2010.

[21] I. Rahwan and G.R. Simari, "Argumentation in Artificial Intelligence," Springer, eds. 2009.

[22] M. M. Rasheed, M. Hasan and M. S. Rahman, "Maximum neighbour voronoi games," in Proc. 3rd International Conference on Algorithms and Computation (WALCOM'09), vol. 5431, 2009, pp. 93–104.

[23] F. Toni, "Argumentative agents," in Proceedings of the International Multiconference on Computer Science and Information Technology (IMCSIT'10), 2010, pp. 223–229.

[24] S. Toulman, Uses of Arguments, Cambridge University Press, 1958.

[25] G. Voronoi, "Nouvelles applications des parametres continus a la theorie des formes quadratiques," J. Reine Angew, Math. 134 (1908), pp. 198–287.