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Voronoi diagrams for automated argumentations among Internet of Things

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Abstract. This work introduces a novel approach to display and arbitration of machine to machine abstract argumentation for Internet of Things devices, which does not require human intervention. The proposed model is a hybrid between weighted Dung style argumentation frameworks and competitive facility placement Voronoi games. It can accommodate weights of arguments and attack relations to depict weighted argumentation frameworks, as well as a set of premises for dynamic argumentation frameworks. Included is a visualization tool for the strength of attacks and strength of arguments and a discussion on computational challenges of the paradigm.

Keywords: Machine to machine abstract argumentation, Voronoi game, Internet of Things

1. Introduction

The Internet of Things (IoT) is a network of interconnected smart devices seeking to automate and improve business processes and various aspects of day-to-day life. As the size and price of electronic components dwindle, manufacturers fortify diverse devices to join the smart, online networks. Thus, inter-operability becomes the main concern for the rapidly expanding Internet of Things [32]. The necessity for efficient interaction between autonomous devices gives rise to the need for automated machine-to-machine negotiation. One way to ensure devices successfully communicate and negotiate with each other to achieve individual or common goals is through argumentation.

Argumentation is the process in which agents exchange and evaluate interacting and inevitably conflicting arguments. These arguments contain sets of premises, corresponding methods of reasoning, and the culminations of conclusions drawn from logical reasoning. Argumentation is one of the oldest research foci and one of the most enduring ones in Artificial Intelligence [7,28] and in parallel in Philosophy, first in [34] and most recently in [26]. Abstract argumentation has been a rich and varied recent discipline that started with [8] and is widely credited to [16]. It has been adapted to many domains including computational law [14], machine learning [24], and multi-agent negotiations [17]. The most vigorous and prolific argumentation research has been conducted with Argugrid (www.argugrid.eu),

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We seek to examine abstract argumentation in service of facilitating interaction and haggling among machines arising from the burgeoning introduction of Internet of Things spanning internet of vehicles and smart devices that will soon be pervasive in smart cities. Related work in Section 2 outlines IoT and abstract argumentation basics as well as a review of Voronoi diagrams. Section 3 describes argument construction for machine reasoning and argumentation. Section 4 offers an application of the Voronoi representation for argumentation systems as well as a description of implementation demonstrating the approach. Finally, Section 5 recapitulates this work's contributions.

2. Literature review

2.1. The Internet of Things

The term Internet of Things is used to describe a system where the Internet is connected to the physical world via ubiquitous sensors and actuators. The resulting pervasive network is comprised of numerous machine agents equipped with sensors and the ability to perceive context. The agents must have the ability to communicate with one another in order to make decisions on behalf of users or systems and to proactively take action. Even though the IoT is currently largely vertical [32] and heterogeneous, the expectation is that in the future smart devices will seamlessly network with each other [23] behind the scenes. Machine IoT agents require automated negotiation as they interact in an open environment and either have different and possibly conflicting goals or must parlay with each other to form dynamic alliances. Some applications also require decision making on the operational level, for which automation is vital [31]. IoT devices are autonomous machine agents in multi-agent systems.

Automated negotiation in multi-agent systems based on argumentation has been found to be superior to other approaches [27]. Various argumentation protocols for negotiation between autonomous agents have been proposed – protocols based on dialogue [6], embedded dialogue [12], plan modification [33], and roles and contexts [20].

2.2. Argumentation frameworks

Invariably, independent decision making leads to differing arguments pit against one another in conflict, termed attacks in abstract argumentation. Argumentation seeks to pool contradictions into a common arena and strives to arbitrate among them to suggest a desirable configuration (i.e., extension). When the arguing group is made up of humans, human reasoning leads the process. However, when the group is comprised of machines, the argumentation process has to be abstracted in order to be successfully employed in negotiation. Human level reasoning can be transformed into computational argumentation by abstracting arguments and the relations between them. These abstract argumentation frameworks provide the transition between human argumentation and machine to machine multi-agent negotiation. Dung style argumentation is a well-known model for the abstract argumentation process [16]. 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 [26] 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.

1. Subset A' is an *acceptable* set with respect to a set 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 [25]. 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, 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 [16]. However, this approach does not migrate well for scenarios where arguments are not equal. In most cases, an argument will at least weaken a conflicting argument but will not necessarily negate it completely.

2.3. *Extensions of argumentation frameworks*

In order to address the lack of relativity, it is prudent to augment arguments with weights. Weighted argumentation frameworks are an extension of Dung's setup and 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.

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

[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.

attackers and defenders [22]. 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 co-exist. The addition of an inconsistency budget metric adds flexibility to the level of tolerance of attacks with total weight below a certain threshold [15]. Attack weights can also be used to derive defense, acting as a de-facto preference relation [11]. Sophisticated argumentation models therefore profit from the ability to simultaneously attach weights to both arguments and attack relations.

Under certain conditions, arguments need to be temporarily excluded from the framework but not be given zero weight permanently. Dynamic argumentation frameworks [30] are an extension of the classical Dung style approach. They introduce evidence as a deciding factor for which arguments are currently active, and thus valid, and which arguments are not. As premises in argumentation may change, sets of arguments providing evidence to satisfy the premise are activated and deactivated as appropriate.

2.4. Voronoi game

Multi-player argumentation – both cooperative and adversarial, human and machine – can be represented well with a game. A game-theoretical approach can be used determine parameters within a framework [22], but the choice of an appropriate model can do more than that. 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 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. The Voronoi game can be adapted to visually represent weighted argumentation frameworks as well. By placing the argumentation framework in a game setting, this approach allows machine-to-machine negotiation in the IoT to unfold without outside supervision. In its essence, 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 [13,35]. 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 essentially 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 [9]. 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

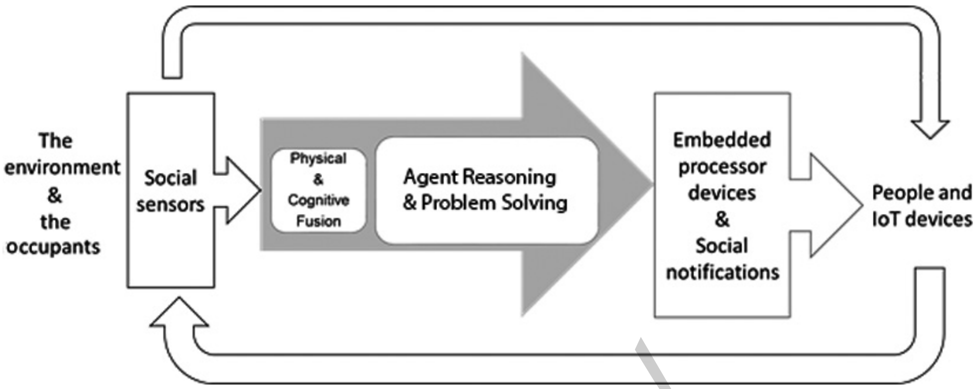

Fig. 1. An agent corresponding to a smart IoT device.

certain winning margin is an NP-hard problem [18]. 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 [29]. 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.

3. Arguments for Internet of Things

The emerging internet of smart devices, also known as cyber physical systems, is a collection of active machine agents interacting with one another and proactively making decisions and taking action. Each agent is designed to receive sensory data and perform problem solving that produces an output, which might be a mere perception or an action to perform.

The module shown in Fig. 1 is an expert system that encapsulates agent problem solving. Agents fuse one or more pieces of sensory data to determine an input for reasoning. The expert system includes design and a model of current applicable conditions. In the context of smart Internet of Things devices, the first task is to identify arguments generated by their corresponding agent. A periodically generated argument is a pair of sensed data and an output encapsulated as an atomic abstract argument that will be cast to compete with other arguments in the system argument pool.

Since an agent's objectives are often a compatible set for the welfare of the agent, it might be possible to prioritize among them. Therefore, the winning arguments from competing objectives would inherit priorities of their corresponding objectives. Otherwise, we can use multi-objective techniques such as the multi-objective particle swarm [10].

Consider an argument illustrated in Fig. 2 with the structure of <sensed condition, then warrant; therefore, recommended action> in accordance with the Toulmin model of argumentation [34] shown in Fig. 3. The warrant portion is simplified here for illustration purposes only.

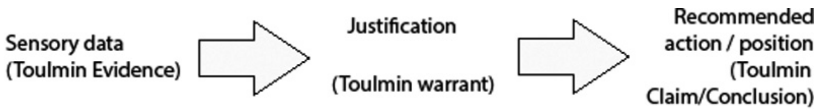

Fig. 2. Components of an argument.

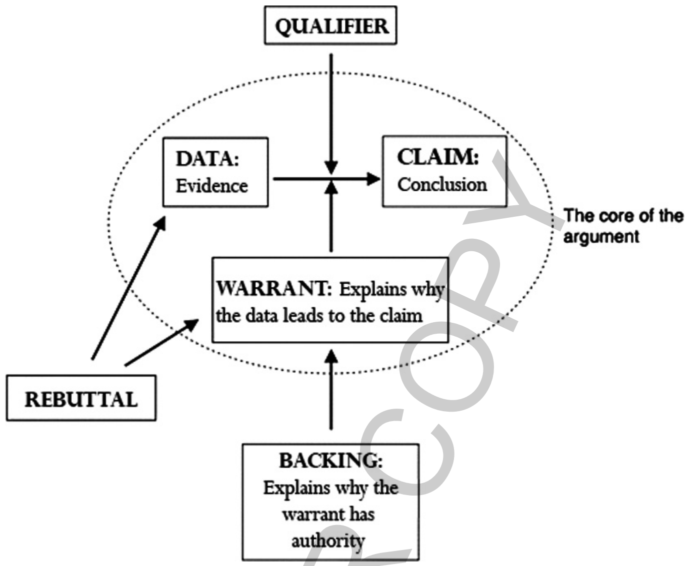

Fig. 3. Components of the Toulmin model of argumentation.

For a given domain, consider an expert system that is typically structured as a set of rules partitioned into subsets to be either in the form <**if** condition-x **then** conclusion-y> for situation assessment purposes, or in the form <**if** conclusion-y **then do** action-k> for action selection purposes. A "condition-x" is a combination of conditions sensed in the environment, a "conclusion-y" is a perception, and an "action-k" is an action to be performed. An inference system is the component of the expert system that gathers conditions that match the "condition-x" part of rules. It then fires the applicable rules and then determines an overall situation as a winning "conclusion-y". Inference works on all applicable action rules that arbitrate among competing actions to determine a winning "action-k" to be executed. Results of running inference on the expert system yield argument components. Overall an argument will be constructed in the form: <since condition-x, then conclusion-y; therefore, recommended action-k>.

Consider the following three arguments where warrants are produced as a result of using a model that formulates and propagates danger/safety levels for each room based on model dynamics of a moving assailant posing danger to occupants:

$a_1 =$ Since the room is noisy and there is motion, then the room is dangerous; therefore, you should leave the room.

$a_2 =$ Since the room is quiet and there is no motion, then the room is safe; therefore, you should stay in the room.

$a_3 =$ Since the room smells of gun powder and there is no motion, then the room is dangerous; therefore, you should leave the room.

Irrespective of the theme and content of arguments, in their abstraction the first two arguments are mutually attacking but may be designated with different weights. Argument a_3 weakens argument a_2, and by attacking a_2, a_3 defends a_1. The resulting argumentation framework comprised of the argument pool and changing conditions is the basis for autonomous agent problem solving. A set of objectives can create inconsistencies for argumentation. Thus far, attacks among arguments discussed earlier are contradictions among arguments that are entirely within a single objective as arguments arise from reasoning with an expert system that is bound to an objective. Occasionally, arguments may arise in multiple objective contexts. Less commonly, attacks between a pair of arguments in one objective may reoccur in another objective framework. However, attacks between arguments that belong to different objectives do not exist.

Argument mining for machine learning and argumentation is currently a topic drawing much interest from a diverse group of research communities [21]. Abstract argumentation is a way to satisfy the need for automation of interactions between Internet of Things devices. Placing the agents in a game setting will provide automatic resolution of contradictory interactions.

4. The Voronoi argumentation game

A Voronoi diagram can model numerous phenomena (cell structure, 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, finite difference methods, distribution of resources, path planning for search and rescue robots 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 a combination of weighted extensions of the Dung-style argumentation framework and dynamic argumentation frameworks.

4.1. The Voronoi argumentation game model

A Voronoi argumentation game model delivers a pictorial representation to weighted abstract argumentation frameworks but its usefulness transcends mere visualization. The game theoretical approach gives agents the opportunity to devise ad-hoc strategies to win the game. Both arguments and attacks can be assigned weights and these weights can be adjusted as the game progresses. The metric determining the outcome of conflicts can be chosen as appropriate depending on the application domain. This approach does not require interaction and can be used for automated negotiation in an IoT multi-agent system. Reshaping of the arena and the inclusion of holes in the play area can be introduced to satisfy a set of pre-determined premises. Holes in the arena will naturally activate and deactivate sets of arguments transforming the framework into a dynamic weighted argumentation framework.

In this novel approach the competitive argumentation game will result in a Voronoi tessellation as shown in Fig. 4. 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. The points within an overlapping portion are absorbed by the region whose site the point is closest to, using Euclidean distance. Thus, the line segment, which is the border between two sites, is exactly midway between them. The Euclidean distance can be replaced by other distance metrics as appropriate. The arena can be reshaped, contain holes, and can exceed two dimensions if the argumentation topic necessitates it. An arbitrary number of players (IoT devices) 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

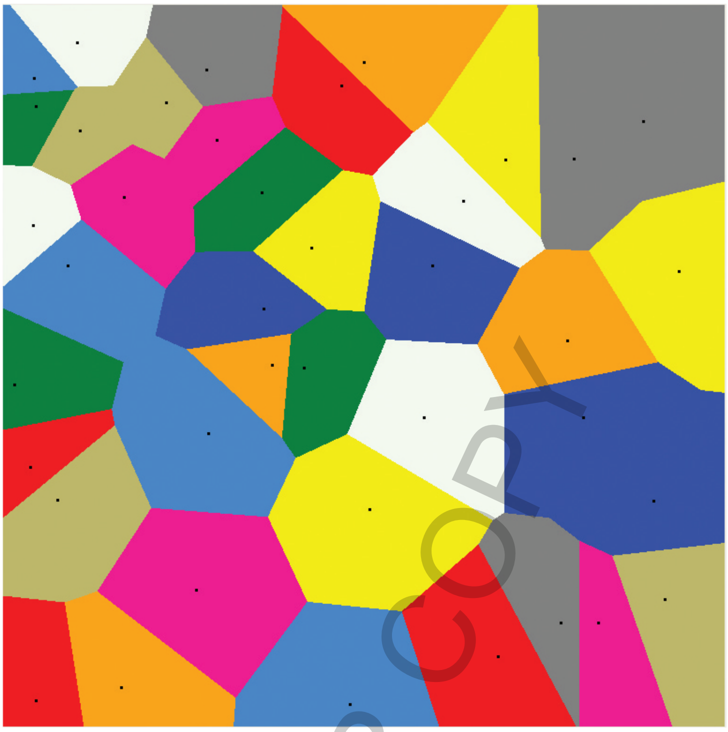

Fig. 4. Example Voronoi tessellation after three rounds with eight players.

intuitive strategy is greedy – the selection of the next argument aims to maximize the total area captured by the player at every round.

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 shown in Fig. 5. The arena can thus be covered by two arguments as well as it could be covered by a number of them, so all of the 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 as depicted in Fig. 6. Assigning each site a radius to reflect the argument strength 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.

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 visual presentation.

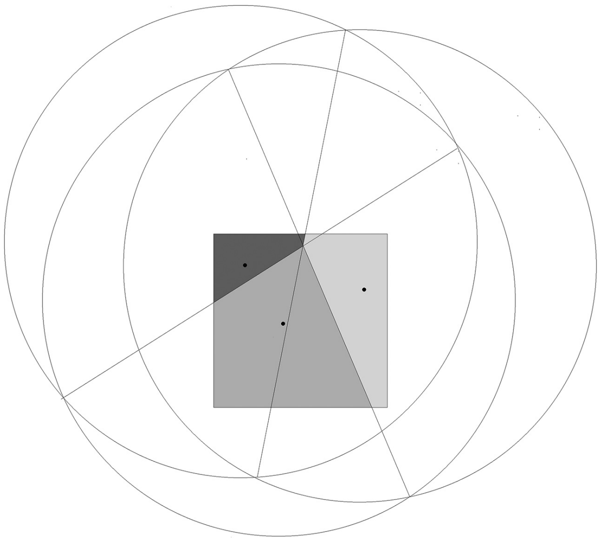

Fig. 5. Formation of a Voronoi tessellation for three arguments of uniform weight.

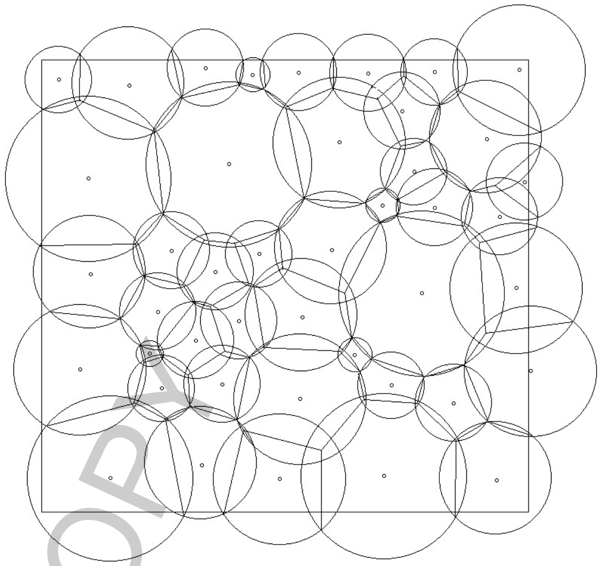

Fig. 6. Formation of Voronoi tessellation for multiple arguments of variable weight.

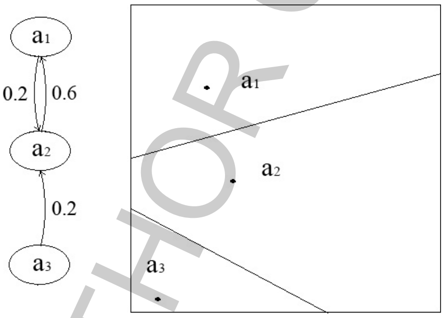

Fig. 7. Example weighted argumentation framework and its Voronoi argumentation game tessellation.

For the smart IoT devices reasoning example from Section 3, an argumentation framework with sample weights ascribed to the attacks relations is shown in Fig. 7. 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. Thus, the remaining attack relation is $a_2 \to a_1$ with recalculated weight of 0.4. 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.

4.2. Prototype

An algorithm has been created to animate the model. Its current functional iteration presented in pseudo-code in Algorithm 1 assumes that all arguments have equal weight. Adding the weight of the

Algorithm 1: Voronoi Argumentation Game

Input: *dimx, dimy*: the dimensions of the 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 $n * a$
Goal: visual representation of the normalized utility obtained by each player after a rounds
declare the player controlling most of the area as the winner

```
1.  create empty playing field with dimensions dimx, dimy
2.  designate a distinctive color for each player c_i
3.  if no moves have been made yet (first move is random)
4.  then player_1 chooses an argument <x_i, y_i> at random
5.      move argument from the argument list into the arena
6.      claim one unit of utility for the first player (no opponents)
7.  end if
8.  for all other moves do (choose the best strategy for player_i)
9.      for all arguments remaining in the argument list do
10.         temporarily create voronoi tessellation and compute the corresponding utility
11.     end for
12.     find the argument with the maximum utility
13.     move the argument from the argument list into the arena
14.     update utility for all players
15. end for
16. declare winner as the player with the most utility u_i
17. function: voronoi
18. for all points in the arena do
19.     compute Euclidean distance from point to all sites in the arena
20.     assign color of the nearest site to the point
21. end for
```

Output: Voronoi tessellation after argumentation game, player utilities, and winner

argument is a future improvement currently in development. The algorithm delivers the step-by-step Voronoi tessellation resulting from each move made by a player. Required input values are the dimensions of the currently rectangular or square arena, the number of players, and the number of arguments per player. Other arena shapes and arenas with holes are a future extension. The spatial coordinates of the arguments are kept in a list and can be generated at random or entered. 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. The algorithm starts by assigning the first player a random argument from the list (steps 3–7), as the first argument always claims the entire arena. In truth that puts the player at a disadvantage. A consideration for future improvement is giving him the opportunity to select an argument with a site as close to the center of the argumentation arena as possible. Since the output is graphic, the most intuitive way to represent the play area is with a pixel grid. 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

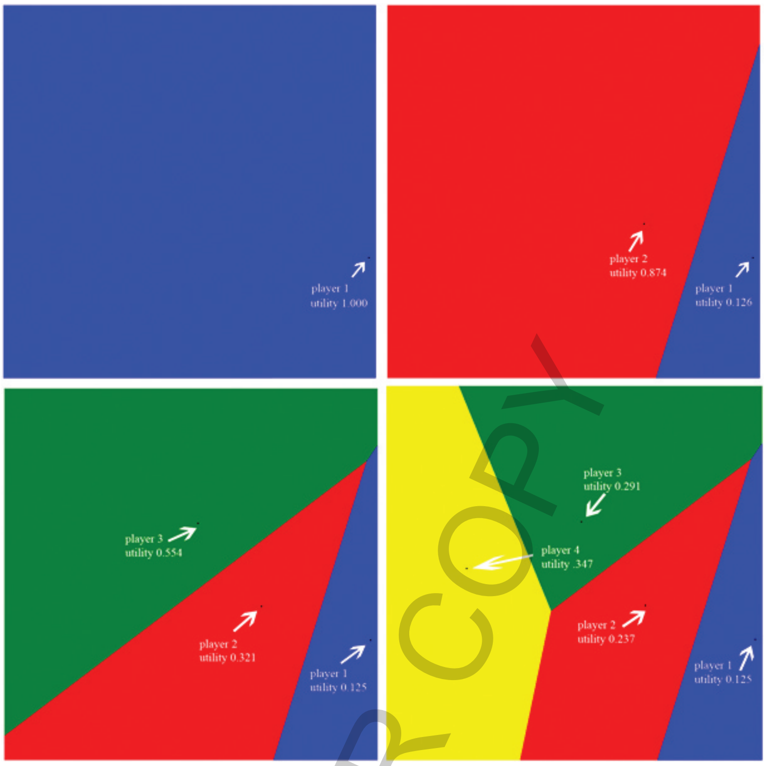

Fig. 8. First four rounds in a sample Voronoi argumentation game.

creates their tessellations and computes the resulting normalized utility – the number of pixels captured divided by the total number of pixels in the arena (steps 9–11). For accuracy, since all argument sites receive a uniform color (e.g. black) to mark their coordinates and they can never be captured, the pixels representing sites 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 (steps 12–14), and takes the argument out of the list of possible moves.

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 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.

The algorithm began as a test procedure to deliver the visualization of the argumentation game if all players chose arguments from the argument list at random. Therefore, the design and implementation in their current form do not place emphasis on efficiency. As the layer of best arguments selection was added, the algorithm became impractical for large numbers of players and/or arguments. Planned optimizations include replacing the Voronoi function with Fortune's algorithm [19]. This efficient algorithm uses a sweep line to compute the tessellation in $O(n \log n)$ time. Even with this improvement, argument selection for every player in every round will still present a computational burden. It is possible to only compute the additional utility achieved by each new argument in the subarea of the arena that its Voronoi cell will occupy. This localized computation will ease the complexity of the next best argument selec-

Fig. 9. Outcome of a sample 10 player 50 argument Voronoi argumentation game.

tion and is a future improvement in consideration. The choice of data structures and language can also affect performance. Since this paper's focus is not the algorithm but the model, further computational complexity concerns are left out.

4.3. Simulations

Below are a few example runs of the algorithm. The first of three rounds of the 7 player 21 argument game in Fig. 8 immediately shows that the choice of the first move can put player 1 at a temporary disadvantage, as the second player will select the site closest to her to secure as much of her utility as possible. However, since this is a multi-round game and the strategy is greedy, this does not take away the possibility of a win for player 1. Figure 9 depicts the outcome of a 10 player 50 argument game in which precisely player 1 is the winner. Therefore the outcome of the game depends largely on the arguments in the framework and their proximity (i.e., strength of attacks) to other arguments.

The graphical user interface is a simple JavaFX implementation overlay for the algorithm. Shown in Figs 10 and 11, player and argument per player numbers are a user selection setting – defaults are set to 2 players and 5 rounds. Controls appear and disappear as appropriate. The game statistics are updated after every round.

The prototype is currently in development to add weights to arguments. The algorithm will be altered to include data on argument site radius, which will represent argument weight as shown in Figs 6 and 12. Parts of the arena may remain unclaimed. Further planned developments include a three dimensional play area and the addition of ad-hoc changes to argument and attack relation in the course of the game. These refinements as well as changes of arena shape and the addition of holes to represent a set of evidence will allow the model to accommodate a dynamic weighted argumentation framework.

Fig. 10. The GUI before start of the game – game parameter controls are active.

Fig. 11. The GUI with a game in progress.

5. Discussion and conclusion

The Voronoi argumentation game is a model aiming to automate resolution of contradictory interactions among the emerging internet of smart devices, also known as the Internet of Things. Arguments arise as results of independent decision making. When there are shared objectives in a group, there will be a need for consensus on differing perspectives modeled as conflicting arguments. This model facilitates arbitration among competing arguments regardless of whether they are all collected at once or trickle in continually over a time period.

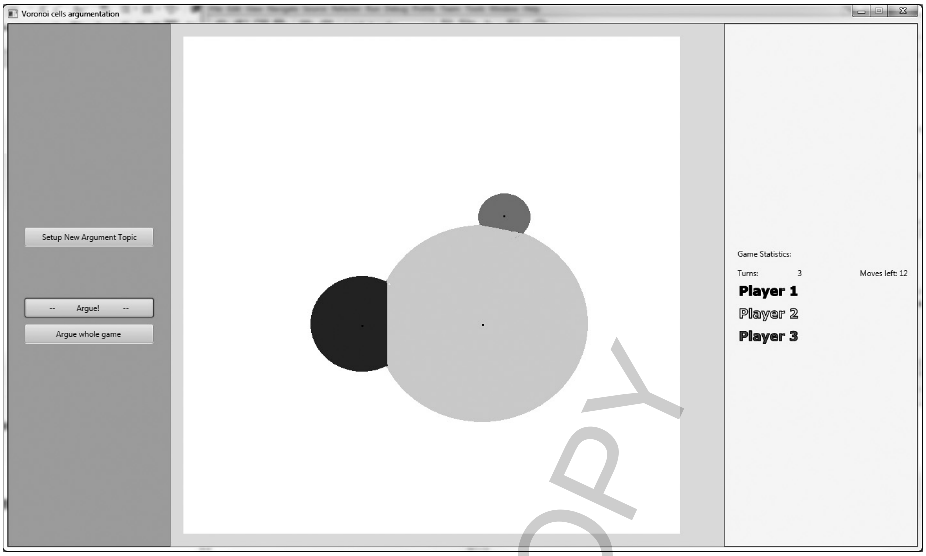

Fig. 12. The Voronoi argumentation game with added strength of arguments.

The Voronoi argumentation game enables depiction of arguments surrounding a shared objective. This is a model for automated 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 accommodate adversarial settings as well as cooperative settings allowing the formation of coalitions. The Euclidian distance metric is a good approximator of argument strengths. However, it can also be replaced with a metric that is more appropriate for the desired application. The arena can be re-shaped to reflect an argumentation topic or a set of premises. The pictorial representation is not only a helpful visualization tool to track the argumentation progress but it also allows agents to independently compute their next best argument to bring forward. The multi-agent negotiation process can be fully automated and allow dynamic changes to the underlying framework. The Voronoi argumentation game is a versatile novel approach to abstract argumentation between multiple autonomous machine agents (devices) in the Internet of Things.

This work introduced rubrics of machine to machine argumentation to facilitate dynamic, online argument synthesis without human intervention. We posit that this will augment grid based computing. A novel Voronoi game setting is presented that provides a visualization tool for strength of arguments. Many challenges are present for machine to machine argumentation (M2MA) deployment and ways in which it needs to be integrated in larger computational models. For any model of M2MA, there is need to formulate an agent utility that accounts for inherent social influences using specific social characteristics.

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