Modeling and Solving Weighted Bipolar Argumentation Problems

Tutorial at the 42nd German Conference on Artificial Intelligence (KI 2019)

Nico Potyka
Roadmap

- Introduction
- Application Examples
- Computational Questions
- Semantical Questions
- Attractor
Buy: 0.5  
Sell: 0.5
Buy: 0.5  

Sell: 0.5
Development of new phone was too expensive. They will have to cut down R&D and will not stay competitive in future.
The new phone is innovative and will increase profits considerably.
Investment in R&D is far beyond competitors' investment. Company is likely to become market leader.
Weighted Bipolar Argumentation Graph (BAG)

- Set of arguments
- Initial weights
- Attack and support relation

**Semantics**: define final strength of arguments based on

- Initial weights and
- Strength of parents

\[ s(i) = f(w(i), \text{Parents}(i)) \]
Computing Strength Values in Acyclic BAGs
- Compute topological ordering
- Evaluate arguments in order

\[ s(i) = f(w(i), \text{Parents}(i)) \]

Computing Strength Values in Cyclic BAGs
- Set initial strength values to initial weights
- Update by applying update formula to all arguments simultaneously
- Repeat until process converges
Semantical Questions
• What properties should final strength values satisfy?
• How can we satisfy these properties?

Computational Questions
• Does update process converge in cyclic BAGs?
• What is the computational performance/complexity?

Applications
• Social Media Analysis
• Decision Support
• Explainable AI
Introduction

Application

Examples

Semantical Questions

Computational Questions

Attractor

Introduction

Semantical Questions
A: The Wonder-Phone is the best new generation phone

B: No, the Magic-Phone is the best new generation phone

C: links to a review of the Magic-Phone giving poor scores due to bad battery performance

D: C is ignorant, since subsequent reviews noted only one of the first editions had such problems: [links].

E: D is wrong. I found C knows about that but withheld the information. Here’s a link to another thread proving it

Social Media Analysis (Leite & Martins 2011)

A: The Wonder-Phone is the best new generation phone

B: No, the Magic-Phone is the best new generation phone

C: links to a review of the M-Phone giving poor scores due to bad battery performance

D: C is ignorant, since subsequent reviews noted only one of the first editions had such problems: [links].

E: D is wrong. I found C knows about that but withheld the information. Here’s a link to another thread proving it

Decision Support (Rago et al. 2016)

Decision Support (Rago et al. 2016)

Issue: How to spend council’s budget?

A1: Build a new cycle path.
A2: Repair current infrastructure.

P1: Cyclists complain of dangerous roads.
P2: A path would enhance the council’s green image.
P3: Potholes have caused several accidents recently.
C1: Significant disruptions to traffic would occur.
C2: Environmentalists are a fraction of the population.
C3: Recent policies already enhance this green image.
C4: Donors do not see the environment as a priority.

Explainable Review Aggregation (Cocarascu et al. 2019)

Explainable Review Aggregation (Cocarascu et al. 2019)

**user:** Why was Phantom Thread highly rated?
**ADA:** This movie was highly rated because the acting was great.
**user:** Why was the acting considered to be great?
**ADA:** The acting was considered to be great because Daniel Day-Lewis was great.
**user:** What did critics say about Daniel Day-Lewis being great?
**ADA:** “...Daniel Day-Lewis remains our greatest actor...”
Modular Semantics (*Mossakowski, Neuhaus 2018*)

- Similar ideas have been considered before
  - Local Gradual Valuations (Amgoud et al. 2008)
  - Semantic Frameworks (Leite, Martins 2011)

DF-QuAD (Rago et al. 2016)

- **Aggregation**: \( a = \prod_{i \in \text{Att}(B)} (1 - s_i) - \prod_{i \in \text{Sup}(B)} (1 - s_i) \)

- **Influence**: \( s = \begin{cases} w + w \times a & \text{if } a < 0 \\ w + (1 - w) \times a & \text{else} \end{cases} \)

---

Some Special Cases: No Parents

- **Aggregation**: $a = 1 - 1 = 0$
- **Influence**: $s = w$
Some Special Cases: No Supporters

- **Aggregation**: \[ a = \prod_{i \in \text{Att}(B)} (1 - s_i) - 1 \leq 0 \]
- **Influence**: \[ s = w + w \times a \leq w \]
Some Special Cases: No Attackers

- **Aggregation:** 
  \[ a = 1 - \prod_{i \in \text{sup}(B)} (1 - s_i) \geq 0 \]

- **Influence:** 
  \[ s = w + (1 - w) \times a \geq w \]
Euler-based Semantics (Amgoud, Ben-Naim 2017)

- **Aggregation:**
  \[ a = \sum_{i \in \text{Sup}(B)} s_i - \sum_{i \in \text{Att}(B)} s_i \]

- **Influence:**
  \[ s = 1 - \frac{1 - w^2}{1 + w \times e^a} \]

Quadratic-energy Model \((KR 2018)\)

- **Aggregation**: \(a = \sum_{i \in \text{Sup}(B)} S_i - \sum_{i \in \text{Att}(B)} S_i\)

- **Influence**:
  \[
  s = \begin{cases} 
  w + (1 - w) \times \frac{a^2}{1 + a^2} & \text{if } a > 0 \\
  w - w \times \frac{a^2}{1 + a^2} & \text{else}
  \end{cases}
  \]

Aggregation Functions

- **Product:** \( \prod_{i \in \text{Att}(B)} (1 - s_i) - \prod_{i \in \text{Sup}(B)} (1 - s_i) \)

- **Sum:** \( \sum_{i \in \text{Sup}(B)} s_i - \sum_{i \in \text{Att}(B)} s_i \)

- **Top:** \( \max \{ s_i : i \in \text{Sup}(B) \} - \max \{ s_i : i \in \text{Att}(B) \} \)
Influence Functions

- **Linear**($k$):
  \[
  \begin{cases}
    w + \frac{w}{k} \times a & \text{if } a < 0 \\
    w + \frac{1 - w}{k} \times a & \text{else}
  \end{cases}
  \]

- **Euler-based**:
  \[
  1 - \frac{1 - w^2}{1 + w \times e^a}
  \]

- **qmax**($k$):
  \[
  \begin{cases}
    w + \frac{1 - w}{k} \times \frac{a^2}{1 + a^2} & \text{if } a > 0 \\
    w - \frac{w}{k} \times \frac{a^2}{1 + a^2} & \text{else}
  \end{cases}
  \]
Semantical Desiderata

• Equivalence
• Neutrality
• Dummy
• Maximality/ Minimality
• Strengthening/ Weakening

• Void Precedence
• Triggering
• Counting
• Proportionality
• ...

• (Baroni et al. 2018) showed that most properties can be broken down to two fundamental principles called Balance and Monotonicity

1. If attackers and supporters are „equally strong“, strength should be equal to initial weight

2. If attackers are „stronger (weaker) than“ supporters, strength should be smaller (larger)
Balance: DF-QuAD

• Aggregation: \( a = (1 - 1) - (1 - 1) = 0 \)

• Influence: \( s = 0.5 + (1 - 0.5) \times 0 = 0.5 \)
Balance: DF-QuAD

- **Aggregation:** $a = (1 - 0.8) - (1 - 1) = 0.2$
- **Influence:** $s = 0.5 + (1 - 0.5) \times 0.2 = 0.6$
Balance: DF-QuAD

- **Aggregation:** $a = (1 - 1) - (1 - 1) \times (1 - 1) = 0$

- **Influence:** $s = 0.5 + (1 - 0.5) \times 0 = 0.5$

*Product Aggregation and Top Aggregation can violate balance*
Monotonicity (Intuition)

1. *If the „same impact“ (in terms of initial weight, attack and support) acts on A1 and A2, then they should have the same strength.*

2. *If the impact on A1 is „more positive“, then it should have a larger strength than A2.*
Monotonicity: Euler-based Semantics

- \( a = -0.5 \)
- \( s = 1 - \frac{1 - 0.5^2}{1 + 0.5 \times \exp(-0.5)} \approx 0.42 \)

- \( a = -1 \)
- \( s = 1 - \frac{1 - 0.5^2}{1 + 0.5 \times \exp(-1)} \approx 0.37 \)
Monotonicity: Euler-based Semantics

- **A**: 0.5
  - **B**: 1

  \[ a = -0.5 \]
  \[ s = 1 - \frac{1 - (-1)^2}{1 + 1 \times \exp(-0.5)} = 1 \]

- **C**: 1
  - **D**: 1

  \[ a = -1 \]
  \[ s = 1 - \frac{1 - (-1)^2}{1 + 1 \times \exp(-1)} = 1 \]

*Euler-based Influence violates monotonicity in boundary cases*
• **Duality:** Attack and support should behave „in a dual manner“

• **Open-Mindedness:** strength should become arbitrarily close to 0 (1) if we keep adding „strong“ attackers (supporters)
Duality: DF-QuAD

- \( a = (1 - 0.8) - 1 = -0.8 \)
- \( s = 0.5 - 0.5 \times 0.8 = 0.1 \)

- \( a = 1 - (1 - 0.8) = 0.8 \)
- \( s = 0.5 + (1 - 0.5) \times 0.8 = 0.9 \)
Duality: Euler-based

A: 0.8

B: 0.5

Euler-based Influence can violate Duality

\[
\begin{align*}
\text{B: } & 0.5 \\
\text{a: } & -0.8 \\
s: & 1 - \frac{1 - 0.5^2}{1 + 0.5 \times \exp(-0.8)} = 0.39
\end{align*}
\]

\[
\begin{align*}
\text{C: } & 0.8 \\
\text{D: } & 0.5 \\
\text{a: } & 0.8 \\
s: & 1 - \frac{1 - 0.5^2}{1 + 0.5 \times \exp(-0.8)} = 0.65
\end{align*}
\]
Open-Mindedness: DF-QuAD

• $a = (1 - 1) - 1 = -1$
• $s = 1 - 1 \times 1 = 0$

• $a = 1 - (1 - 1) = 1$
• $s = 0 + (1 - 0) \times 1 = 1$
Definition in (AAMAS 2019) does not capture this case accurately.
Open-Mindedness: Euler-based

- $a = -n \to -\infty$

- $s = 1 - \frac{1 - 0.5^2}{1 + 0.5 \times \exp(-n)} > 0.25$

Euler-based Influence can violate Open-Mindedness
## Summary: Potential Semantical Problems

### Aggregation Function

<table>
<thead>
<tr>
<th>Aggregation Function</th>
<th>Balance</th>
<th>Monotonicity</th>
<th>Duality</th>
<th>Open-Mindedness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>(×)</td>
<td>(×)</td>
<td></td>
<td>(×)</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>(×)</td>
<td>(×)</td>
<td></td>
<td>(×)</td>
</tr>
</tbody>
</table>

### Influence Function

<table>
<thead>
<tr>
<th>Influence Function</th>
<th>Balance</th>
<th>Monotonicity</th>
<th>Duality</th>
<th>Open-Mindedness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euler-based</td>
<td>(×)</td>
<td>×</td>
<td></td>
<td>×</td>
</tr>
<tr>
<td>qmax</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Aggregation/Influence Function

<table>
<thead>
<tr>
<th>Aggregation/Influence Function</th>
<th>Balance</th>
<th>Monotonicity</th>
<th>Duality</th>
<th>Open-Mindedness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum/qmax</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Some Further Readings about Weighted Semantics

• **Attack-only Graphs**


• **Support-only Graphs**


• **Bipolar Graphs**

Introduction

Application Examples

Computational Questions

Semantical Questions

Attractor
Computing Strength Values

\[ i \leftarrow 0 \]

\textbf{FOR} \( a = 1, \ldots, n \)

\[ s^{(i)}(a) = w(a) \]  \hspace{1cm} \text{Initialization with initial weights}

\textbf{DO}

\[ i \leftarrow i + 1 \]

\textbf{FOR} \( a = 1, \ldots, n \)

\[ s^{(i)}(a) = f(w(a), \text{Parents}(a), s^{(i-1)}(a)) \]  \hspace{1cm} \text{Update strength values simultaneously until convergence}

\textbf{UNTIL} \( |s^{(i)} - s^{(i-1)}| < \varepsilon \)

\[ s \leftarrow s^{(i)} \]
**Depth in Acyclic BAGs**

*Depth*(i) is defined as

\[
\begin{align*}
\text{Depth}(i) & = 0 & \text{if Parents}(i) = \emptyset \\
& = 1 + \max \{ \text{depth}(j) : j \in \text{Parents}(i) \} & \text{else}
\end{align*}
\]
Lemma
If depth(A)=d, then strength of A remains unchanged after iteration i.

Theorem
In acyclic BAGs, strength values converge in n-1 iterations.

Theorem
Computing strength values once according to topological ordering yields the same result.

O(n^2) updates
O(n+m) for ordering + O(n) updates
Convergence in Cyclic BAGs

- In cyclic BAGs, algorithm may not converge (Mossakowski, Neuhaus 2018)

Digression: Lipschitz Continuity

- **Lipschitz-continuous**: “function does not grow faster than some linear function”
  
  \[ |f(x_1) - f(x_2)| \leq \lambda \times |x_1 - x_2| \]
  
  for all \( x_1, x_2 \)

- \( \lambda \) is called **Lipschitz-constant**
Convergence in Cyclic BAGs

• **Sufficient conditions for converge can be derived assuming**
  • *bounded derivatives* (Mossakowski, Neuhaus 2018) or, more general,
  • *Lipschitz-continuity* (AAMAS 2019)

**Theorem (AAMAS 2019)**

If semantics is contractive, that is,
1. aggregation function has Lipschitz-constant $\lambda_1$,
2. influence function has Lipschitz-constant $\lambda_2$,
3. $\lambda_1 \times \lambda_2 < 1$,
then the algorithm is guaranteed to converge.

Convergence up to D digits after $O( C(\lambda_1, \lambda_2) \times D)$ iterations

Some Lipschitz Constants

<table>
<thead>
<tr>
<th>Aggregation Function</th>
<th>( \lambda )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>max. indegree of any argument in BAG</td>
</tr>
<tr>
<td>Sum</td>
<td>max. indegree of any argument in BAG</td>
</tr>
<tr>
<td>Top</td>
<td>( \leq 2 )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Influence Function</th>
<th>( \lambda )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear((k))</td>
<td>( \frac{1}{k} \max {w(i), 1 - w(i) : i = 1, \ldots, n} )</td>
</tr>
<tr>
<td>Euler-based</td>
<td>0.25</td>
</tr>
<tr>
<td>qmax((k))</td>
<td>( \frac{1}{k} \max {w(i), 1 - w(i) : i = 1, \ldots, n} )</td>
</tr>
</tbody>
</table>
Some Convergence Guarantees

<table>
<thead>
<tr>
<th>Semantics</th>
<th>Aggregation</th>
<th>Influence</th>
<th>Sufficient Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Mossakowski, Neuhaus 2018)</td>
<td>Top</td>
<td>Euler-based</td>
<td>Always</td>
</tr>
<tr>
<td>DF-QuAD (k=1)</td>
<td>Product</td>
<td>Linear(k)</td>
<td>Max. indegree &lt; k</td>
</tr>
<tr>
<td>Euler-based</td>
<td>Sum</td>
<td>Euler-based</td>
<td>Max. indegree &lt; 4</td>
</tr>
<tr>
<td>Quadratic Energy (k=1)</td>
<td>Sum</td>
<td>qmax(k)</td>
<td>Max. indegree &lt; (\frac{k}{p})</td>
</tr>
</tbody>
</table>
Convergence Guarantees vs. Open-Mindedness

<table>
<thead>
<tr>
<th>Aggregation</th>
<th>Influence</th>
<th>k=0</th>
<th>k=1</th>
<th>k=10</th>
<th>k=100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>Euler</td>
<td>0.9</td>
<td>0.862</td>
<td>0.862</td>
<td>0.862</td>
</tr>
<tr>
<td>Addition</td>
<td>Euler</td>
<td>0.9</td>
<td>0.862</td>
<td>0.811</td>
<td>0.811</td>
</tr>
<tr>
<td>Top</td>
<td>qmax(1)</td>
<td>0.9</td>
<td>0.498</td>
<td>0.498</td>
<td>0.498</td>
</tr>
<tr>
<td>Addition</td>
<td>qmax(1)</td>
<td>0.9</td>
<td>0.498</td>
<td>0.012</td>
<td>0.001</td>
</tr>
<tr>
<td>Top</td>
<td>qmax(5)</td>
<td>0.9</td>
<td>0.873</td>
<td>0.873</td>
<td>0.873</td>
</tr>
<tr>
<td>Addition</td>
<td>qmax(5)</td>
<td>0.9</td>
<td>0.873</td>
<td>0.213</td>
<td>0.004</td>
</tr>
</tbody>
</table>
Lemma (AAMAS 2019)
If semantics is defined by
1. aggregation function that maps to [-B, B],
2. combination function with Lipschitz-constant $\lambda$,
then $|s(i) - w(i)| \leq \lambda \times B$.

### Aggregation Function

<table>
<thead>
<tr>
<th>Aggregation Function</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>[-1, 1]</td>
</tr>
<tr>
<td>Sum</td>
<td>(-\infty, \infty)</td>
</tr>
<tr>
<td>Top</td>
<td>[-1, 1]</td>
</tr>
</tbody>
</table>

### Influence Function

<table>
<thead>
<tr>
<th>Influence Function</th>
<th>$\lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear(k)</td>
<td>$\geq \frac{1}{2k}$</td>
</tr>
<tr>
<td>Euler-based</td>
<td>$\frac{1}{4}$</td>
</tr>
<tr>
<td>qmax(k)</td>
<td>$\geq \frac{1}{2k}$</td>
</tr>
</tbody>
</table>

Convergence Guarantees vs. Open-Mindedness

- **Constant QuadraticEnergy(∞)**
- **Top/Euler-based QuadraticEnergy(N)**
- **DF-QuAD QuadraticEnergy(100)**
- **Quadratic Energy QuadraticEnergy(10)**
- **Quadratic Energy QuadraticEnergy(N)**
Improving Guarantees by Continuization

- (Discrete) semantics can be seen as coarse approximations of continuous semantics (KR2014)

- Continuizing semantics can solve divergence problems without losing open-mindedness

Improving Guarantees by Continuization

Theorem (AAMAS 2019)
If semantics is contractive (satisfies convergence conditions), continuized semantics converges to the same strength values.

Empirically, convergence in subquadratic time.

Convergence Guarantees for Continuized Semantics

• **Support-only**: yes *(mon. increasing and bounded from above)*

• **Attack-only**: probably *(hand-waving argument)*

• **Bipolar**: maybe *(neither proof idea nor counterexamples are known)*
Some Further Readings about Computational Issues

• **Fixed points in Social Abstract Argumentation**

• **Convergence of Discrete Semantics in Attack-only Graphs**

• **High-Level Introduction to Continuous Semantics**
Attractor

Initialize

Update

arg(buy, 0.5).
arg(sell, 0.5).
arg(A1, 0.8).
arg(A2, 0.7).
arg(A3, 0.9).
att(buy, sell).
att(sell, buy).
sup(a1, sell).
sup(a2, buy).
att(a2, a1).
sup(a3, buy).
att(a3, a1).

BAG

Visualizations

Strength Values

Semantics

Algorithm

Performance

Attractor

https://sourceforge.net/projects/attractorproject/
arg(buy, 0.5).
arg(sell, 0.5).
arg(a1, 0.8).
arg(a2, 0.7).
arg(a3, 0.9).

att(buy, sell).
att(sell, buy).
sup(a1, sell).
sup(a2, buy).
att(a2, a1).
sup(a3, buy).
att(a3, a1).

Buy: 0.5
A2: 0.7
A1: 0.8
A3: 0.9
Sell: 0.5
Solving Weighted Argumentation Problems

```java
AbstractDynamicArgumentationSystem ads = new ContinuousDFQuADModel();

AbstractIterativeApproximator approximator = new RK4(ads);
ads.setApproximator(approximator);

BAGFileUtils fileUtils = new BAGFileUtils();
BAG bag;

try {
    bag = fileUtils.readBAGFromFile(new File("files/PresentationBAG.bag"));
    ads.setBag(bag);
    ads.approximateSolution(10e-3, 10e-4, true);
} catch (Exception e) {
    e.printStackTrace();
}
```
ads.setApproximator(new PlottingRK4(ads));
adss.approximateSolution(10e-3, 10e-4, true);

Generate visualizations with JFreeChart
ads.setApproximator(new PlottingEulersMethod(ads));
ads.approximateSolution(1, 10e-4, true);

Simulate Discrete Semantics using Euler’s Method (KR 2018)

Evolution Continuous DF-QuAD Model, Euler’s Method, d=1.0, e=0.001

BenchmarkUtils benchmark = new BenchmarkUtils();
File benchmarkDirectory = new File("files/networks/barabasi");
QuadraticEnergyModel qas = new QuadraticEnergyModel();
benchmark.runBenchmark(benchmarkDirectory, qas);
Using and Adding Semantics

AbstractDynamicArgumentationSystem

- ContinuousDFQuadModel
- ContinuousEulerBasedModel
- ContinuousModularModel

AggregationFunction
- ProductAggregation
- SumAggregation
- ...

Influence Function
- LinearInfluence
- EulerBasedInfluence
- ...

Using and Adding Algorithms

AbstractIterativeApproximator

Euler's Method

AbstractPlottingIterativeApproximator

Plotting Euler's Method

RK4 (recommended)

Plotting RK4 (recommended)
• **Tutorial Article**


• **Javadoc**

https://sourceforge.net/projects/attractorproject/
Conclusions

Introduction

Application Examples

Semantical Questions

Computational Questions

Attractor
Weighted Bipolar Argumentation

- Computationally efficient tool for
  - Social Media Analysis
  - Decision Problems
  - Explainable AI

- Some interesting research questions
  - convergence guarantees
  - learning BAGs from data
  - empirical investigation of semantical properties
  - new applications
  - ...

https://sourceforge.net/projects/attractorproject/