Explainable and Computationally Efficient Decision Making with Quantitative Abstract Argumentation Frameworks

Tutorial at the 43rd German Conference on Artificial Intelligence (KI 2020)

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Schedule

Small Breaks in between

Questions and comments are very welcome at any time

Block 1 (8:30 – 10:30)

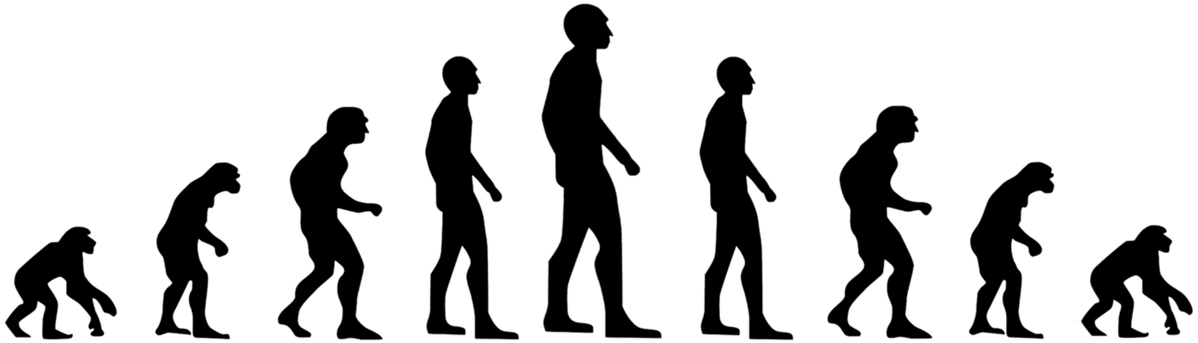
- Overview
- Probabilistic Epistemic Argumentation Overview and Applications
- Gradual Bipolar Argumentation Overview and Applications
- Probabilistic Epistemic Argumentation Advanced Topics

Block 2 (11:00-13:00)

- Gradual Bipolar Argumentation Advanced Topics

A (Biased) Glimpse of Abstract Argumentation

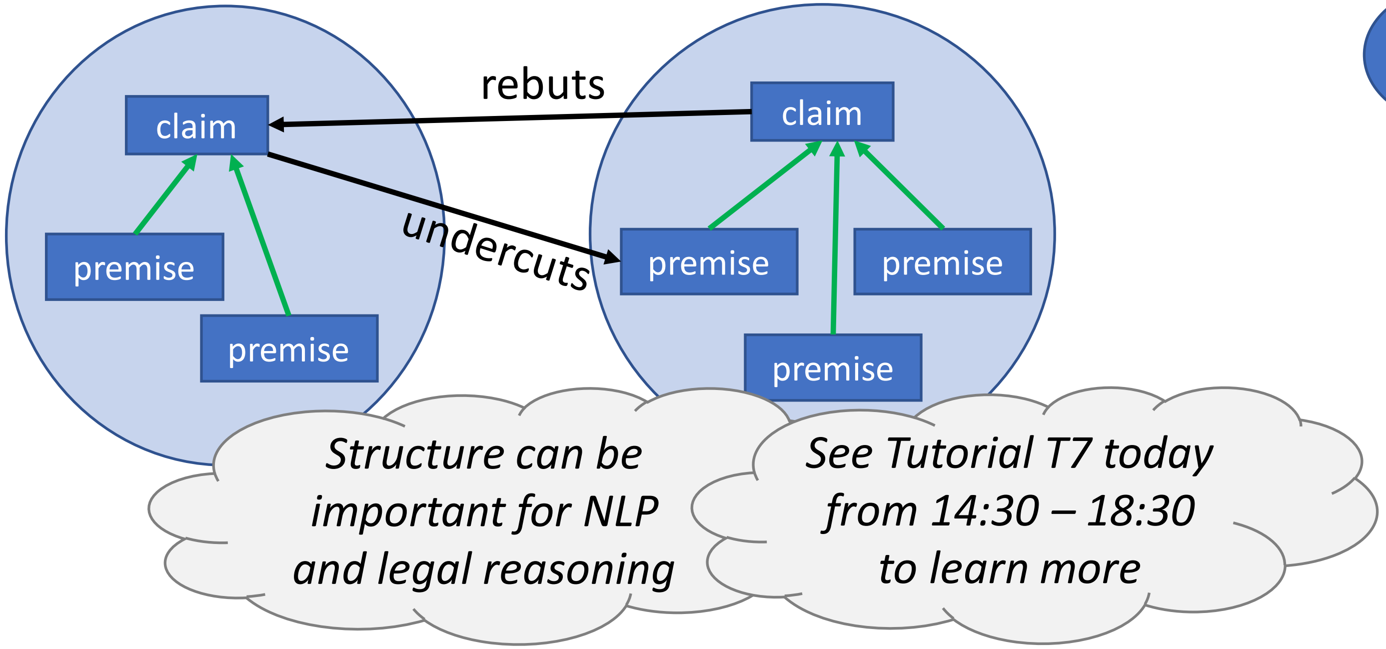
From Dung Frameworks to Quantitative Bipolar Argumentation



Abstract vs Structured Argumentation

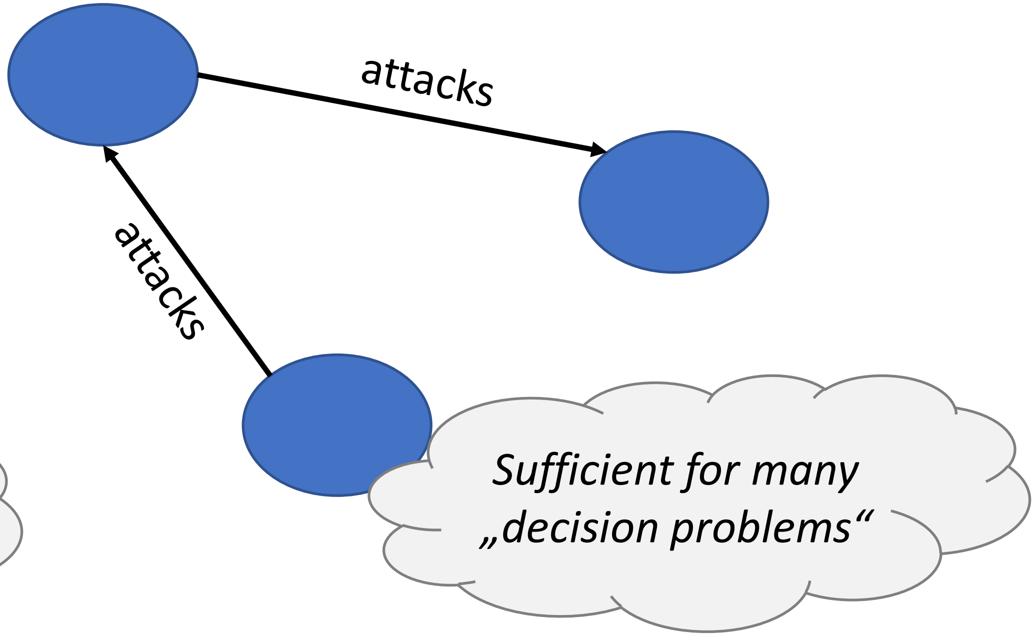
Structured Argumentation

- model internal structure of arguments



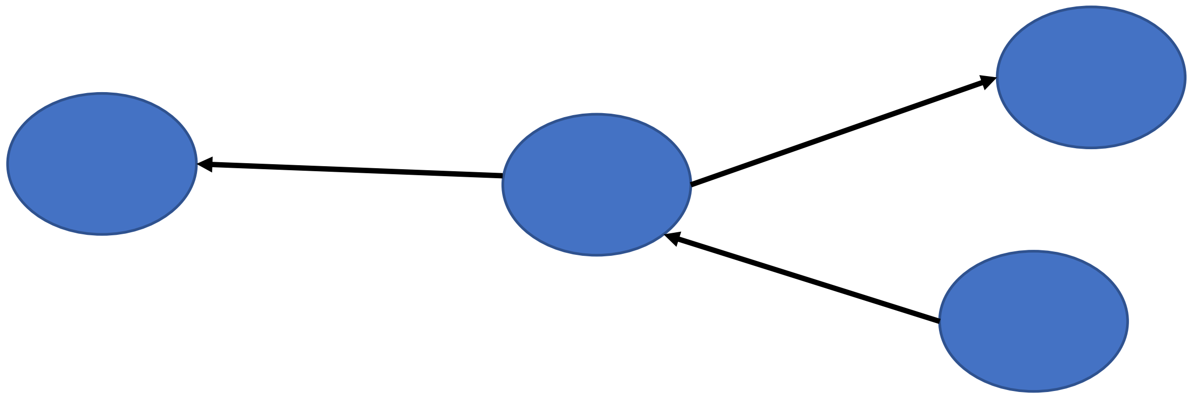
Abstract Argumentation

- Abstract from content, focus on relationships



Dung‘s Abstract Argumentation Framework

- „[…] a statement is believable if it can be argued successfully against attacking arguments.” *[1]*
- **Given** argumentation framework (edges = attacks),

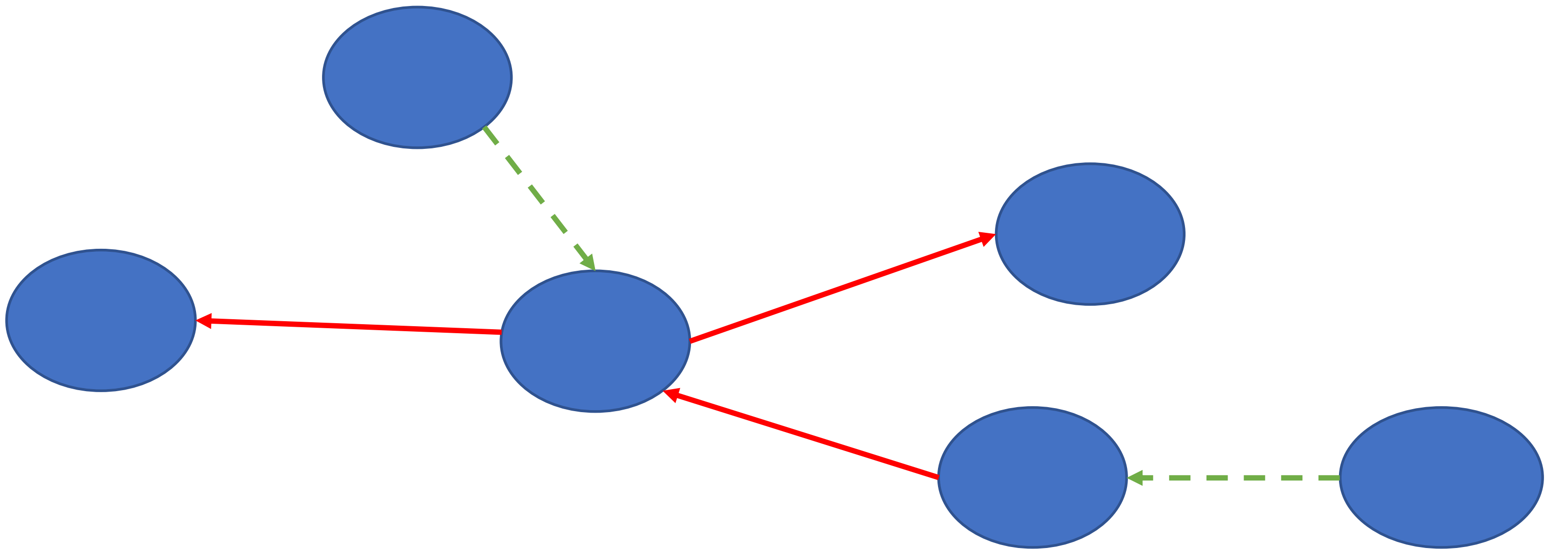


- **Decide** which arguments can be accepted

[1] *Dung, P. M. (1995). On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games. Artificial intelligence, 77(2), 321-357.*

Bipolar Abstract Argumentation

- **Shortcoming:** we do not only consider contra, but also pro arguments
- **Bipolar abstract argumentation** adds support edges *[3]*

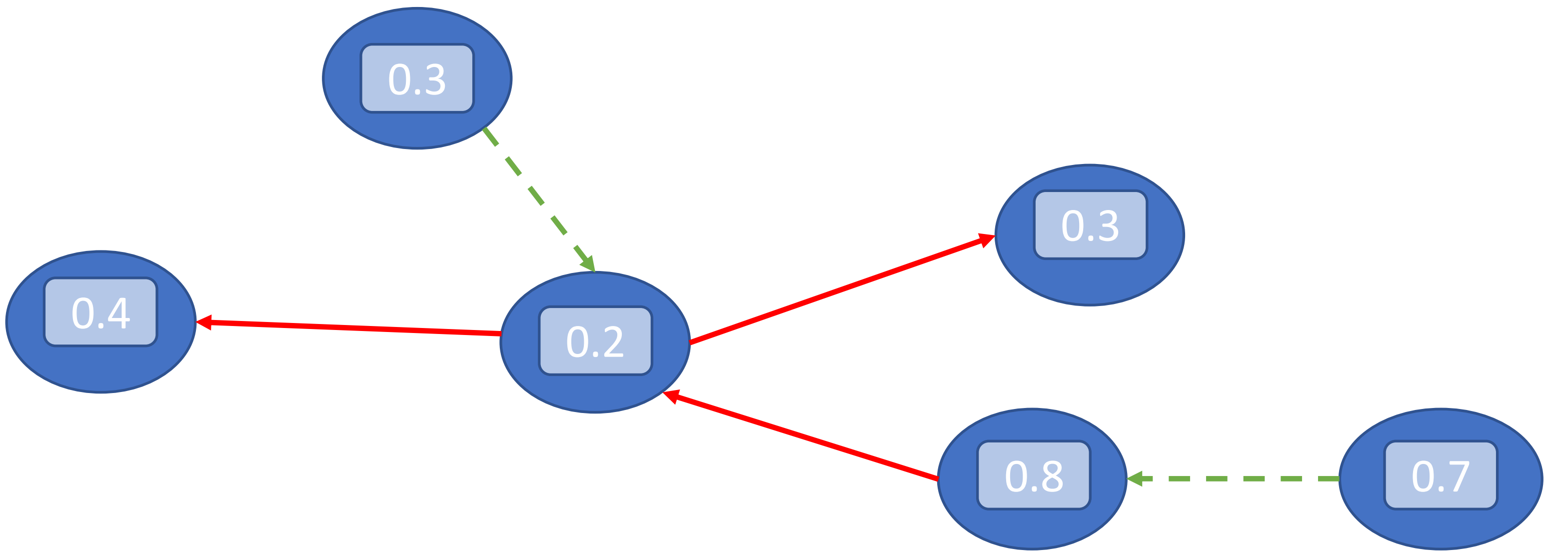


[3] Cayrol, C., & Lagasquie-Schiex, M. C. (2005). On the acceptability of arguments in bipolar argumentation frameworks. In *European Conference on Symbolic and Quantitative Approaches to Reasoning and Uncertainty* (pp. 378-389).

Quantitative Bipolar Abstract Argumentation

- **Shortcoming:** often, we do not completely accept or reject arguments
  Rather, we tend to accept or tend to reject arguments gradually

- **Quantitative frameworks** evaluate arguments numerically



Two Interesting Quantitative Approaches

Probabilistic Epistemic Argumentation

- Evaluation: probabilities
- Complexity: (polynomial)
- Model
  - Bipolar Argumentation Graph
  - Semantical Constraints
- Implementation
  https://sourceforge.net/projects/probabble/

Gradual Bipolar Argumentation

- Evaluation: strength values
- Complexity: (polynomial)
- Model
  - Bipolar Argumentation Graph
  - Initial Weights
  - Update function
- Implementation
  https://sourceforge.net/projects/attractorproject/

Hunter, A., & Thimm, M. (2014). Probabilistic Argumentation with Incomplete Information. In European Conference on Artificial Intelligence (*ECAI)*: 1033-1034.

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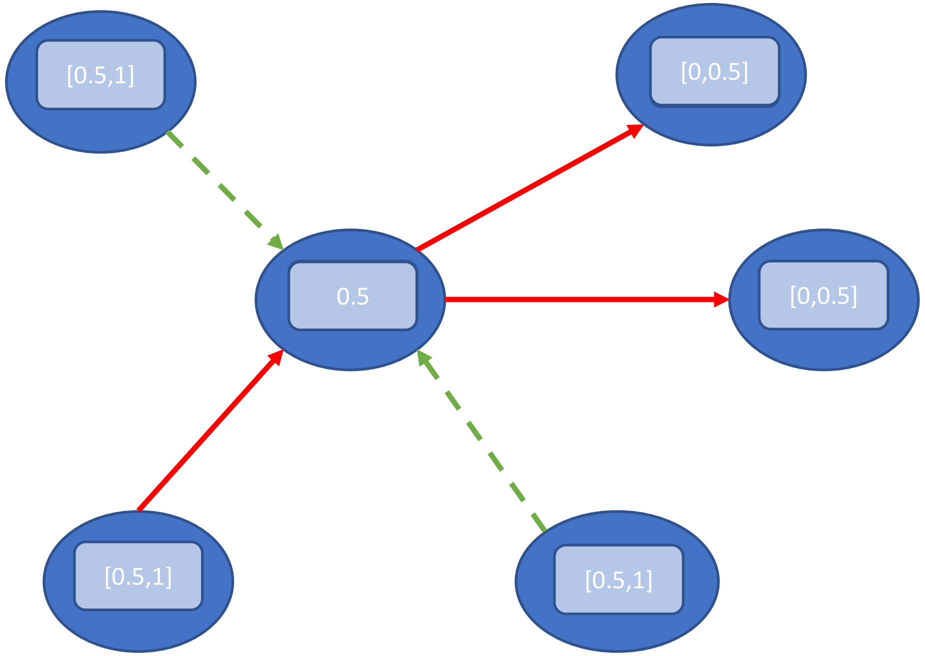
Probabilistic Epistemic Argumentation

Basics and Some Applications

Probabilistic Epistemic Argumentation

- Ingredients
  - BAG
  - Semantical Constraints like
    - Founded: If A unattacked, then $P(A) \geq 0.5$
    - Coherence: If A attacks B, then $P(B) \leq 1 - P(A)$
    - S-Coherence: If A supports B, then $P(\mathrm{A}) \leq P(\mathrm{B})$
    - …

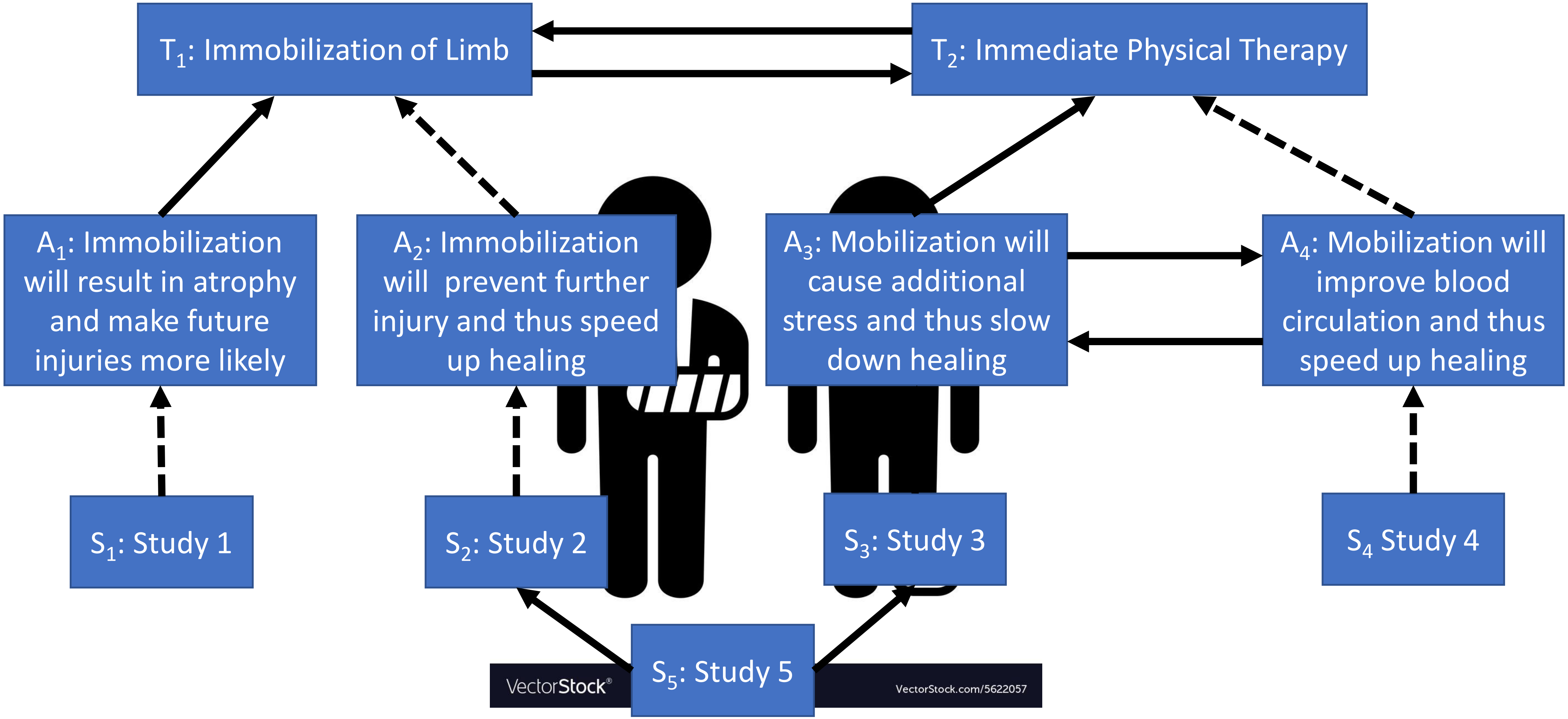


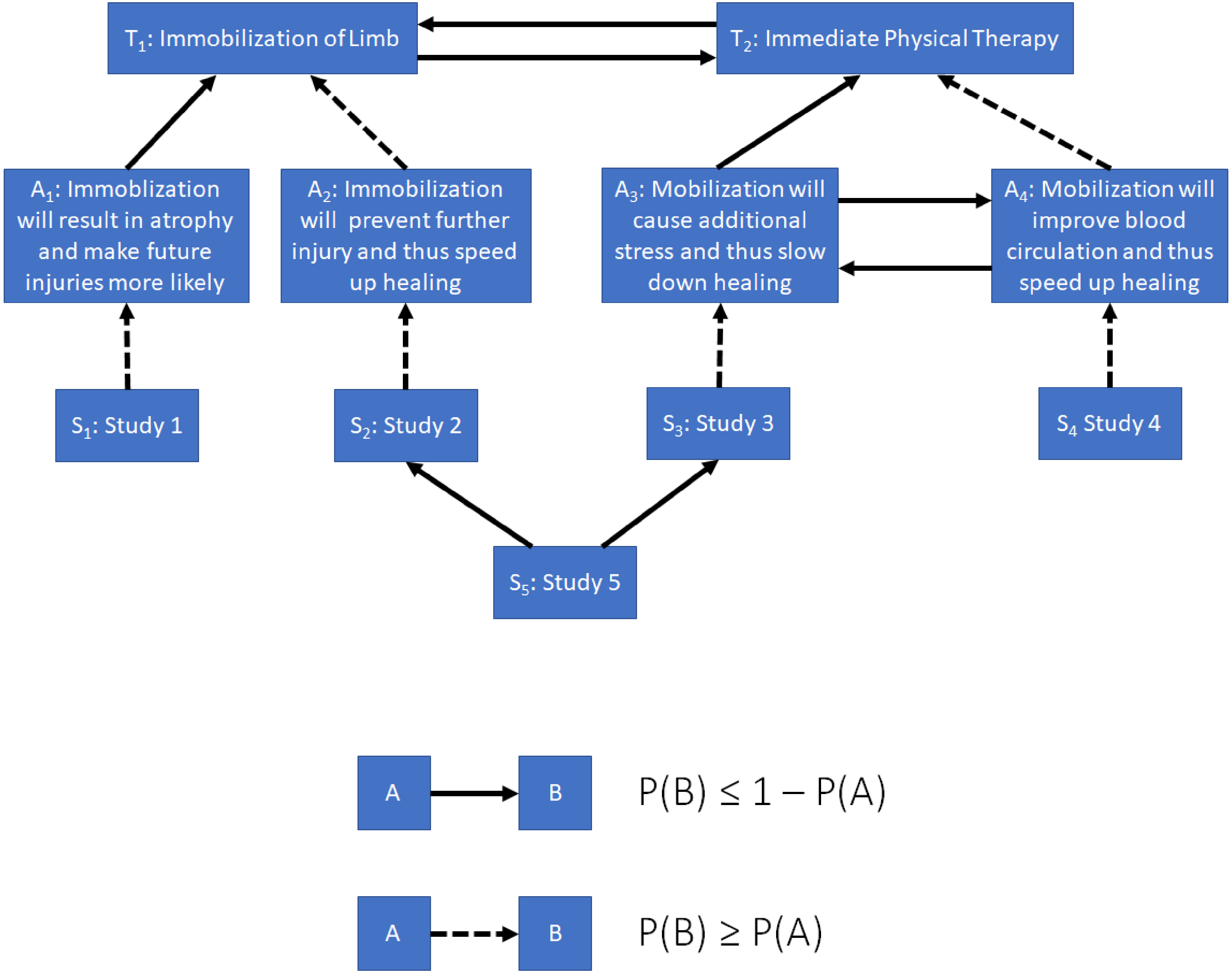
- If all constraints are „linear atomic", solvable in polynomial time *[4]*

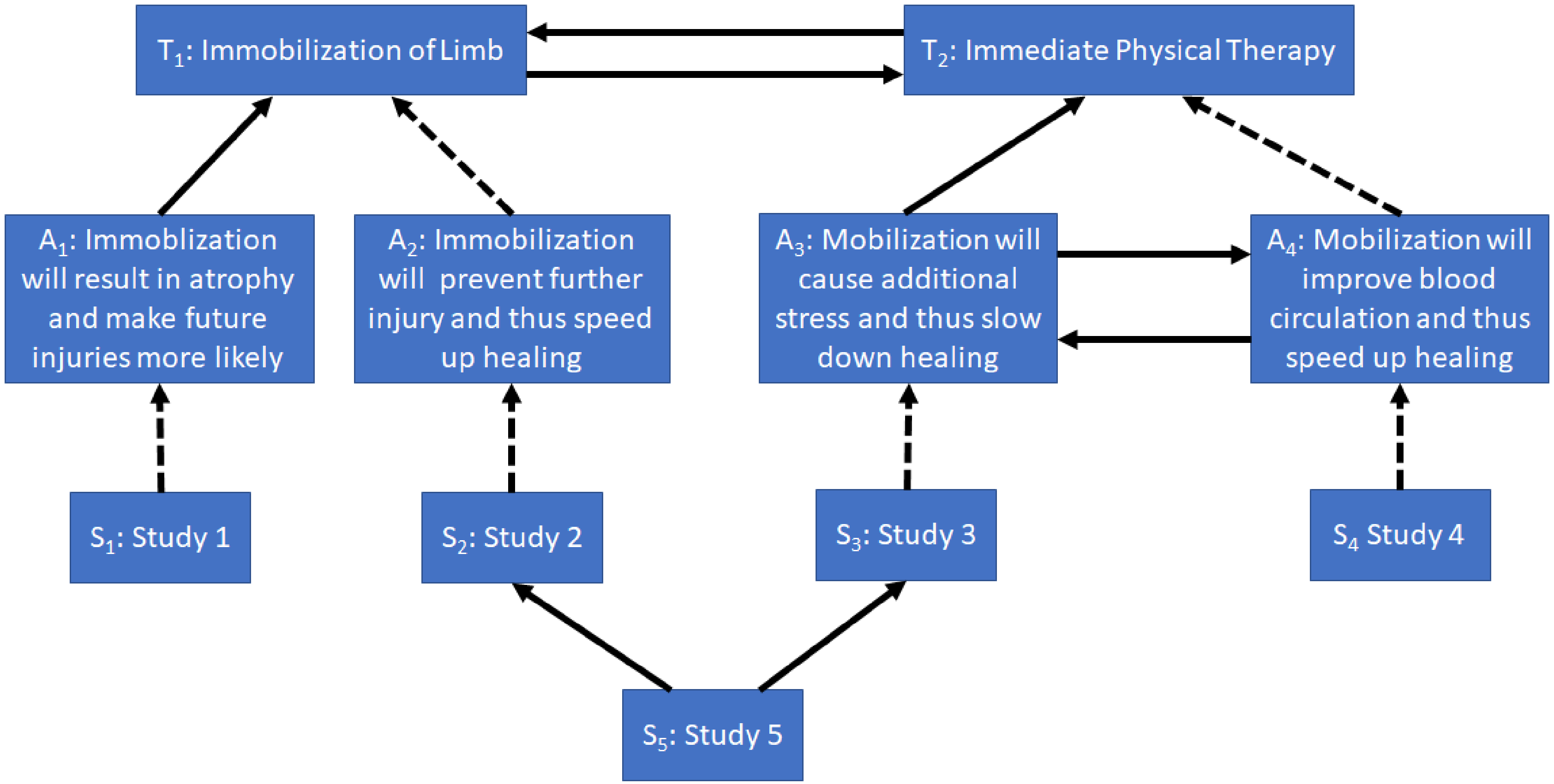
$$\sum_{i=1}^{n} c_i \cdot P(A_i) \leq c_0$$

[4] Potyka, N. (2019). A polynomial-time fragment of epistemic probabilistic argumentation. *International Journal of Approximate Reasoning*, *115*, 265-289.

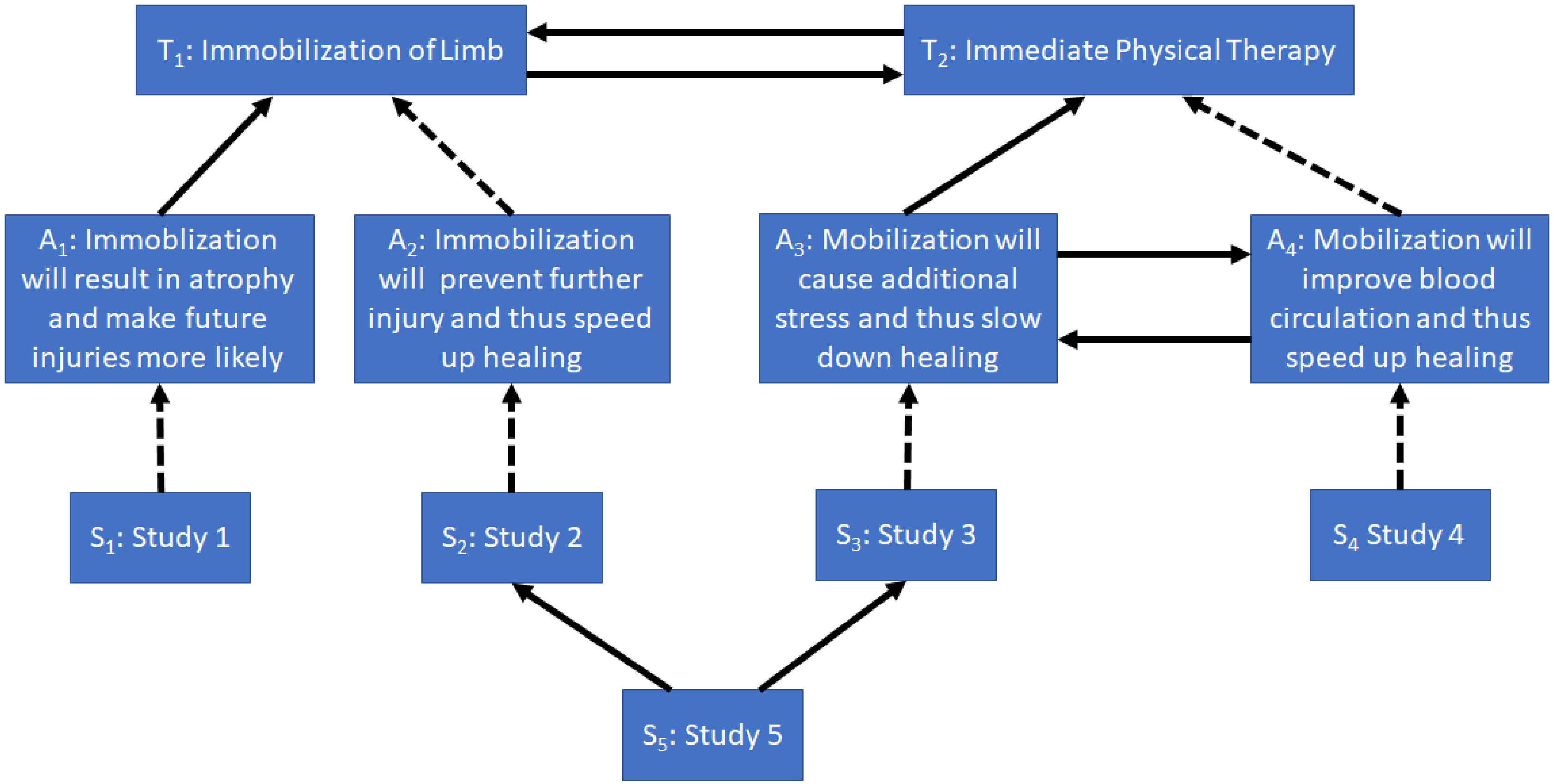
Application: Decision Making



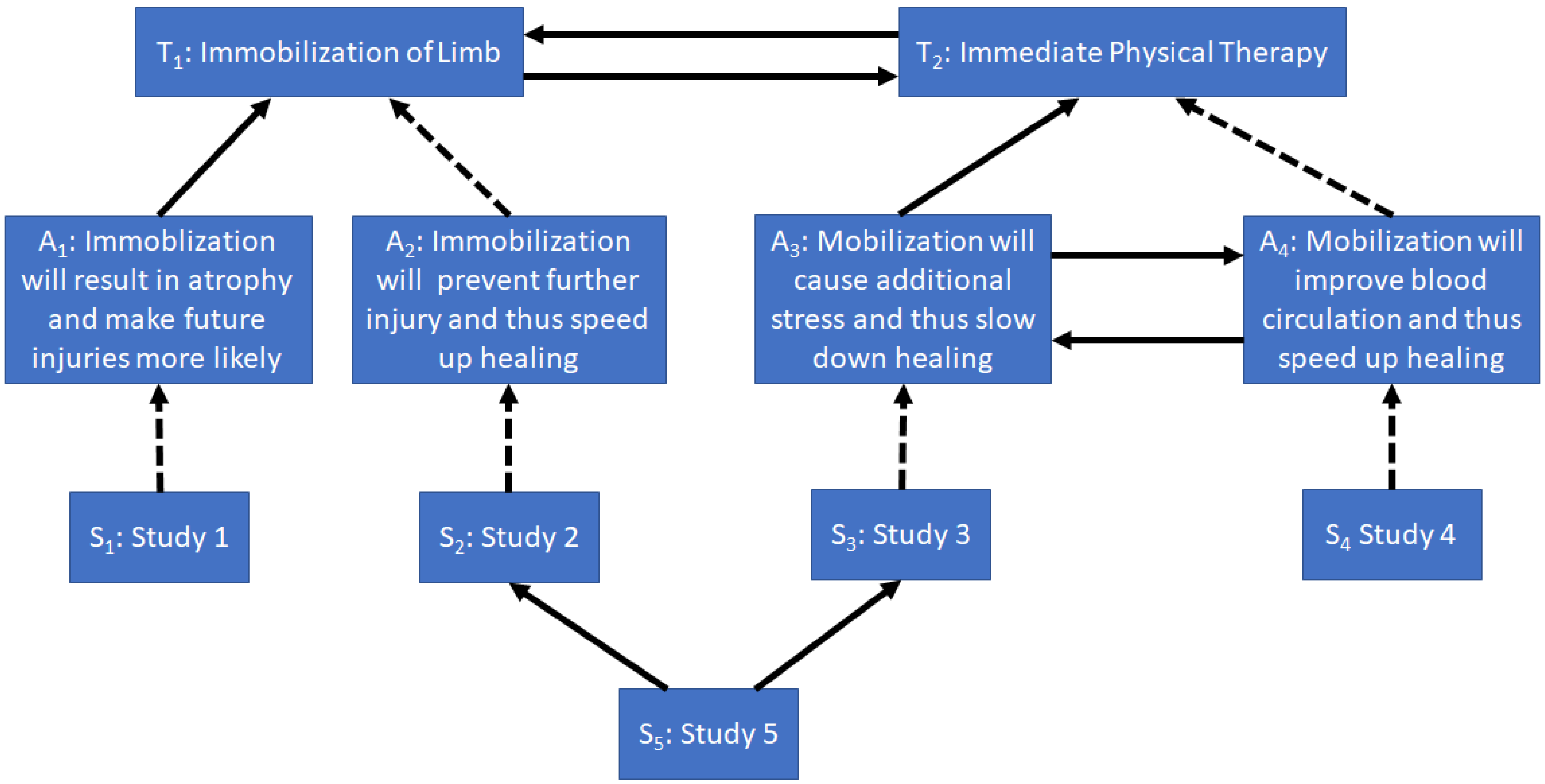

T1: Immobilization of Limb
T2: Immediate Physical Therapy
A1: Immoblization will result in atrophy and make future injuries more likely
A2: Immoblization will prevent further injury and thus speed up healing
A3: Mobilization will cause additional stress and thus slow down healing
A4: Mobilization will improve blood circulation and thus speed up healing
S1: Study 1
S2: Study 2
S3: Study 3
S4 Study 4
S5: Study 5
A
B
P(B) ≤ 1 – P(A)
A
B
P(B) ≥ P(A)



	T_1	T_2	A_1	A_2	A_3	A_4	S_1	S_2	S_3	S_4	S_5
{}	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]

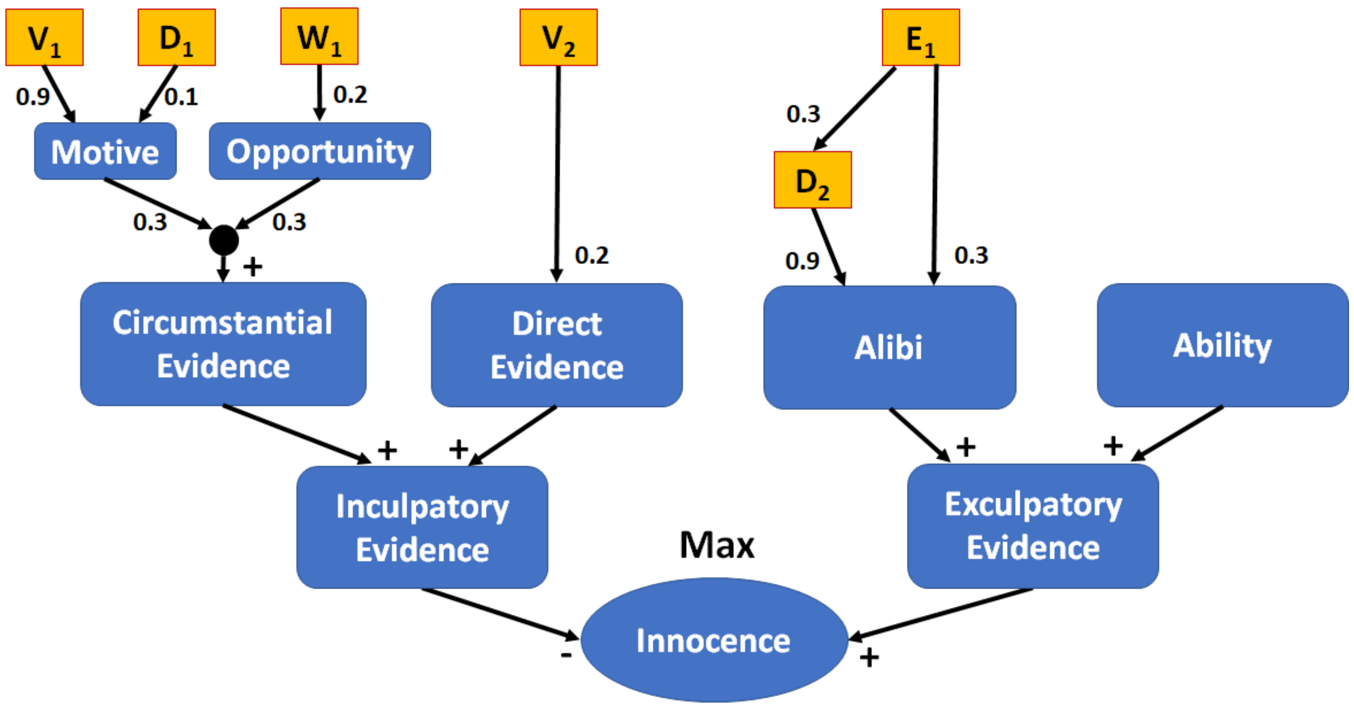


	T_1	T_2	A_1	A_2	A_3	A_4	S_1	S_2	S_3	S_4	S_5
{}	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]
$\{P(S_i) \geq 0.5 \mid i = 1,\ldots,5\}$	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5



	T_1	T_2	A_1	A_2	A_3	A_4	S_1	S_2	S_3	S_4	S_5
{}	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]
$\{P(S_i) \geq 0.5 \mid i = 1,\ldots,5\}$	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
$\{P(S_1) = 1\}$	0	[0,1]	1	0	[0,1]	[0,1]	1	0	[0,1]	[0,1]	[0,1]

Application: Belief Consolidation



$\mathcal{A}$
Innocence
E_{inc}
E_{ex}
E_c
E_d
Alibi
Ability
Motive
Opportunity
$V1$
$V2$
$D1$
$D2$
$W1$
$E1$

Ibs, I. & Potyka, N. (2020). Explainable Automated Reasoning in Law using Probabilistic Epistemic Argumentation. Workshop on Models of Legal Reasoning (MLR 2020).

Application: Computational Persuasion

Hunter, A. (2015). Modelling the Persuadee in Asymmetric Argumentation Dialogues for Persuasion. IJCAI 2015: 3055-3061

Since you do little excercise, you should do a regular excercise class

When I do exercise, I get very hungry and I put on weight

When I do exercise, I get hungry and I put on weight.

Strongly Agree

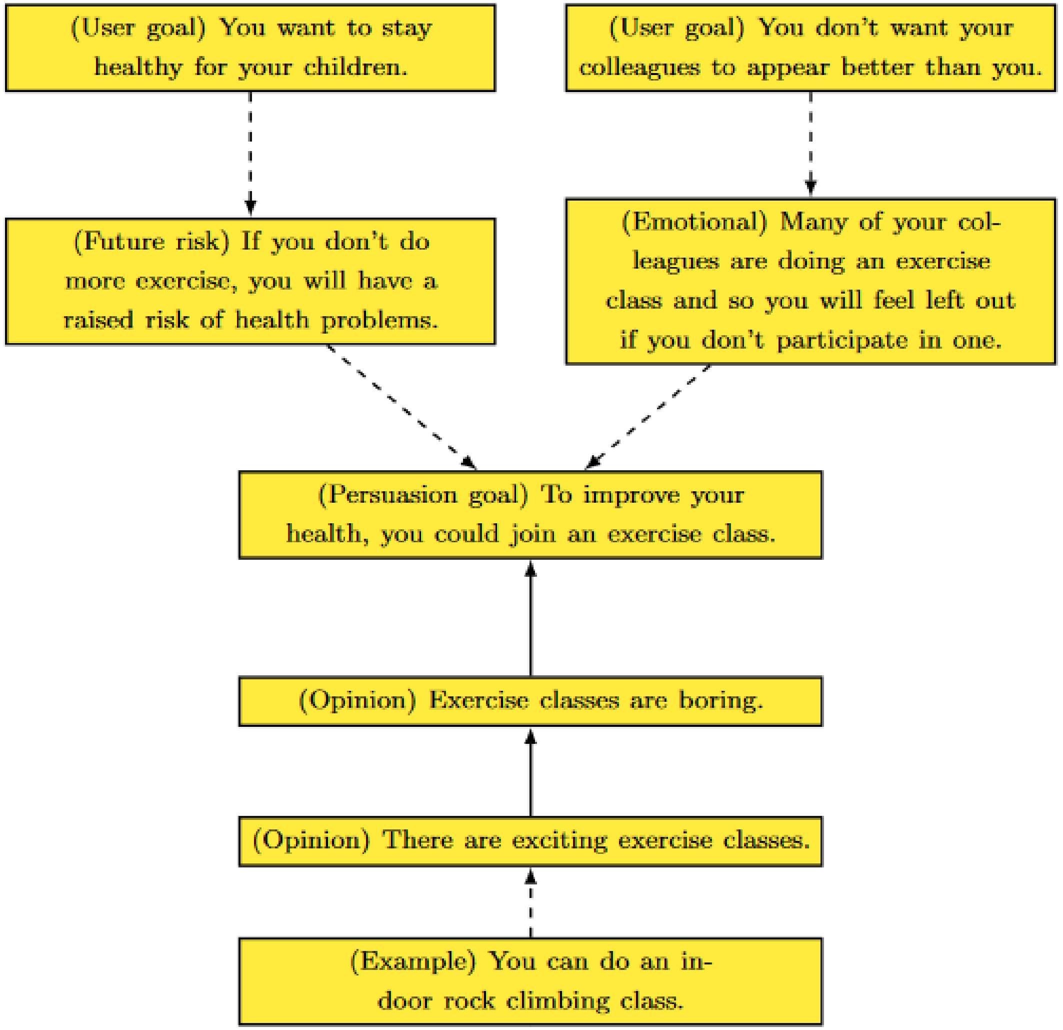
Agree

Indifferent

Disagree

Strongly Disagree

Argumentation Graph



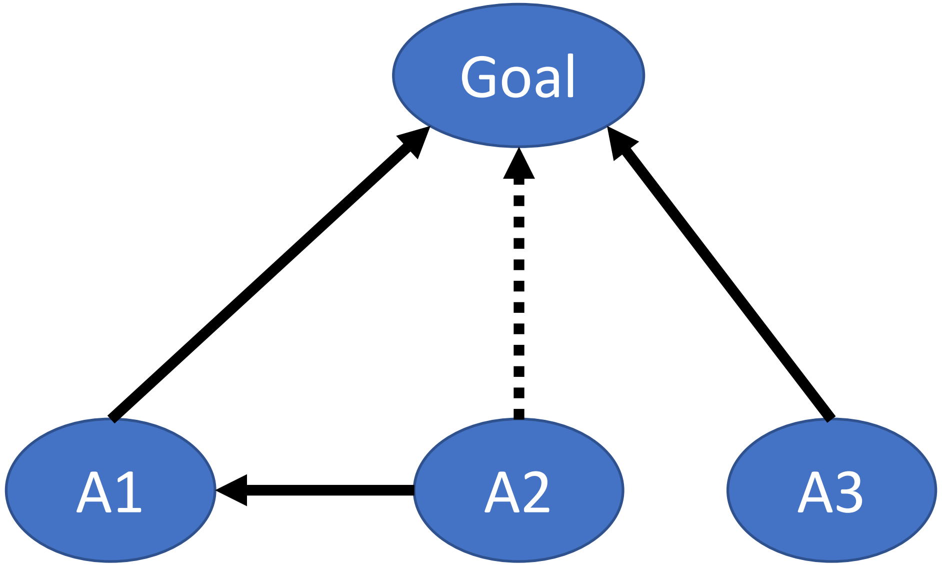
You want to stay healthy for your children.

- Strongly Agree
- **Agree**
- Indifferent
- Disagree
- Strongly Disagree

If you don’t do more exercise, you will have a raised risk of health problems.

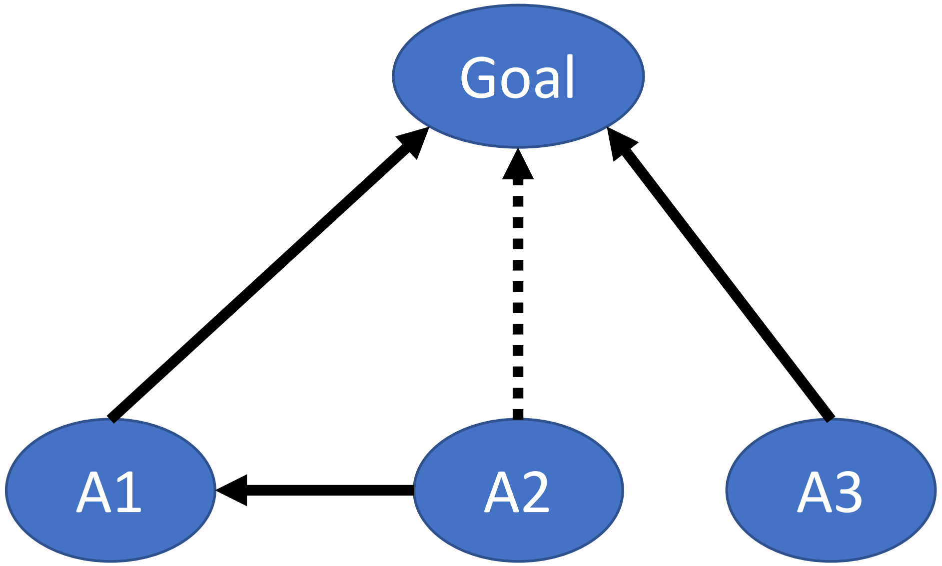
User Model

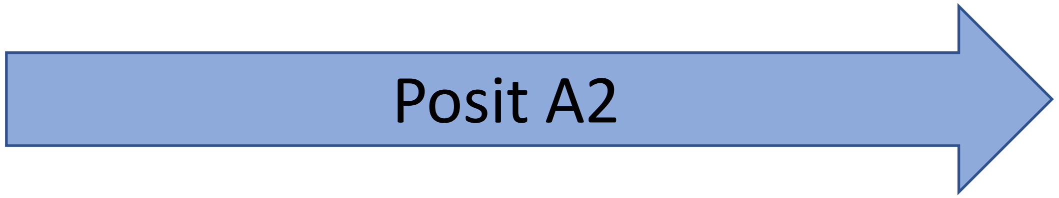
Argument	Belief
A1	0.8
A2	0.1
A3	0.2
Goal	0.2



User Update in Dialogue

Argument	Belief
A1	0.8
A2	0.1
A3	0.2
Goal	0.2





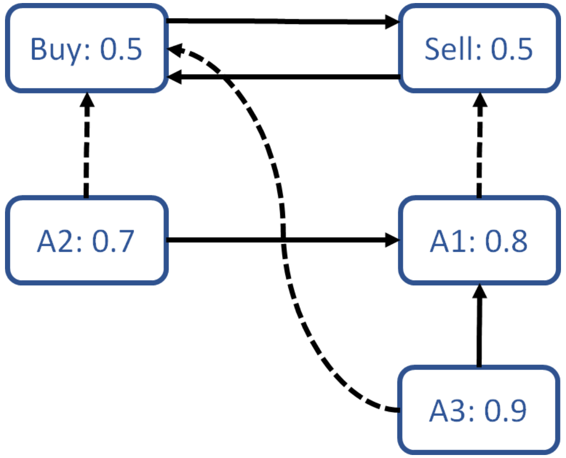
Argument	Belief
A1	0.4
A2	0.6
A3	0.2
Goal	0.7

Gradual Bipolar Argumentation

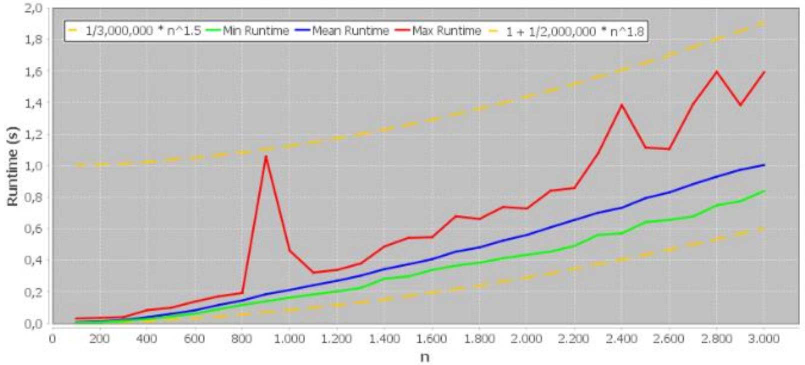
Basics and Some Applications

Gradual Bipolar Argumentation

- Ingredients
  - BAG
  - Initial Weights
  - Update Function

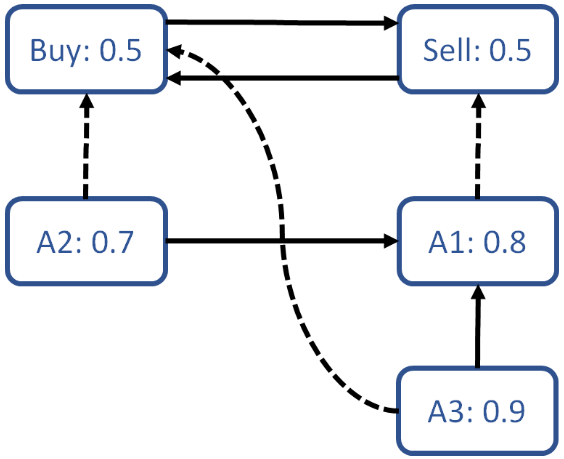


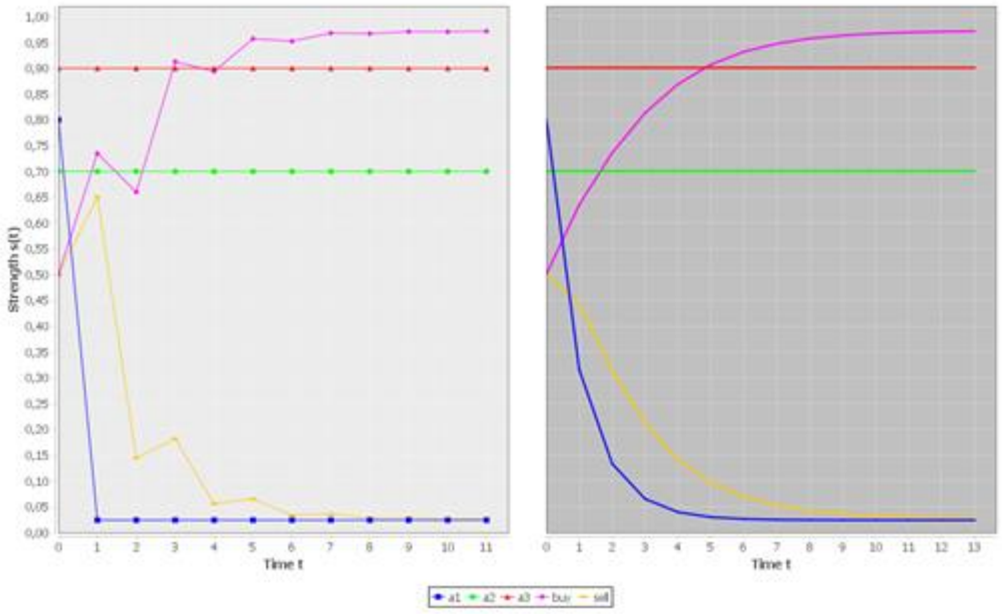
- In many interesting cases, solvable in polynomial time *[3]*

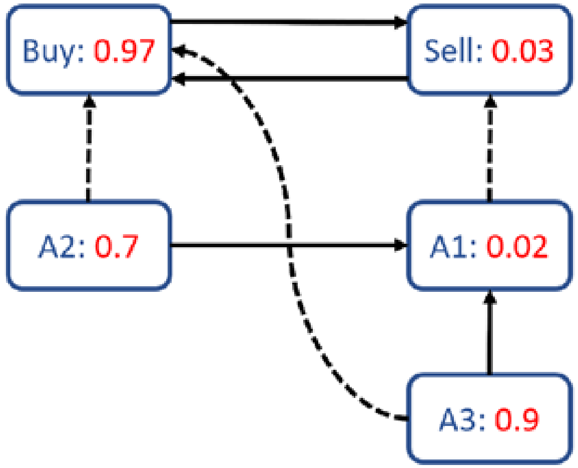


[3] Potyka, Nico. Continuous dynamical systems for weighted bipolar argumentation (2018). Sixteenth International Conference on Principles of Knowledge Representation and Reasoning (KR): 148-157.

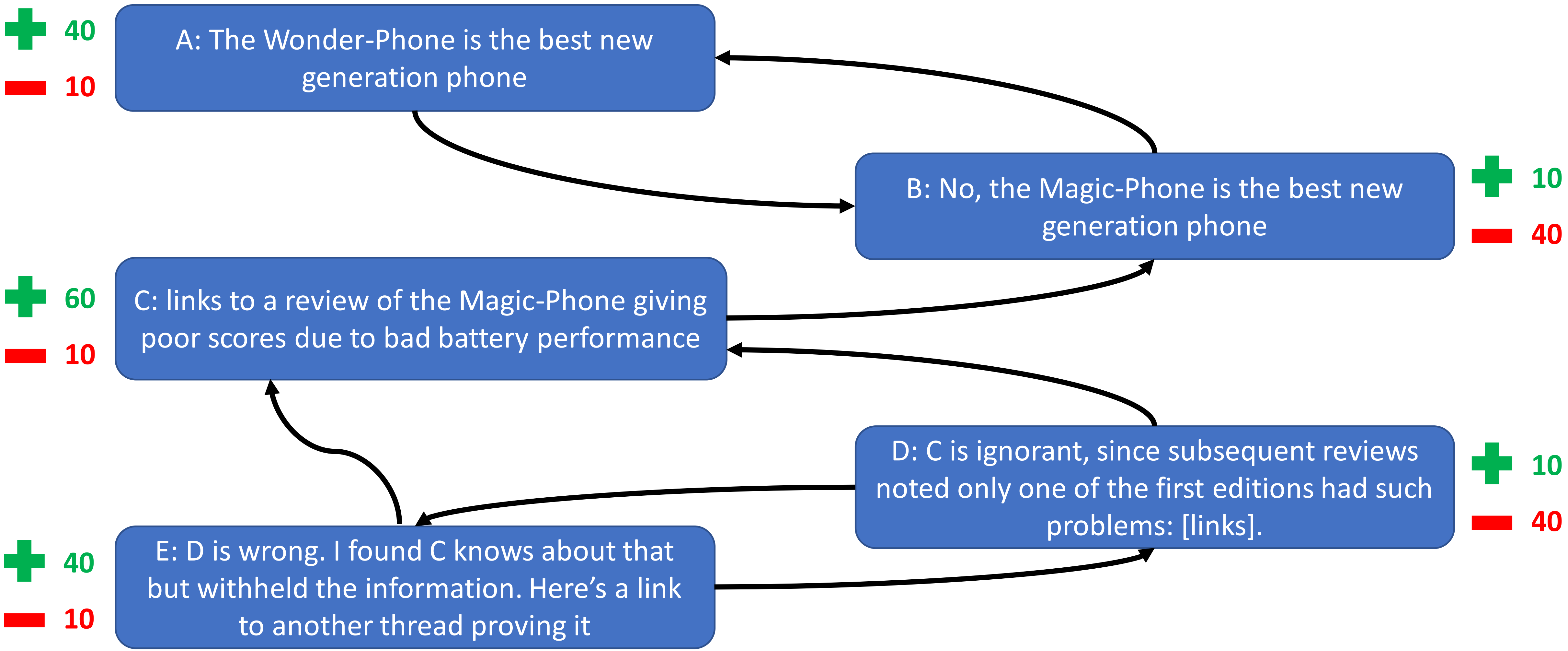
Computing Final Strength Values







Social Media Analysis (Leite & Martins 2011)



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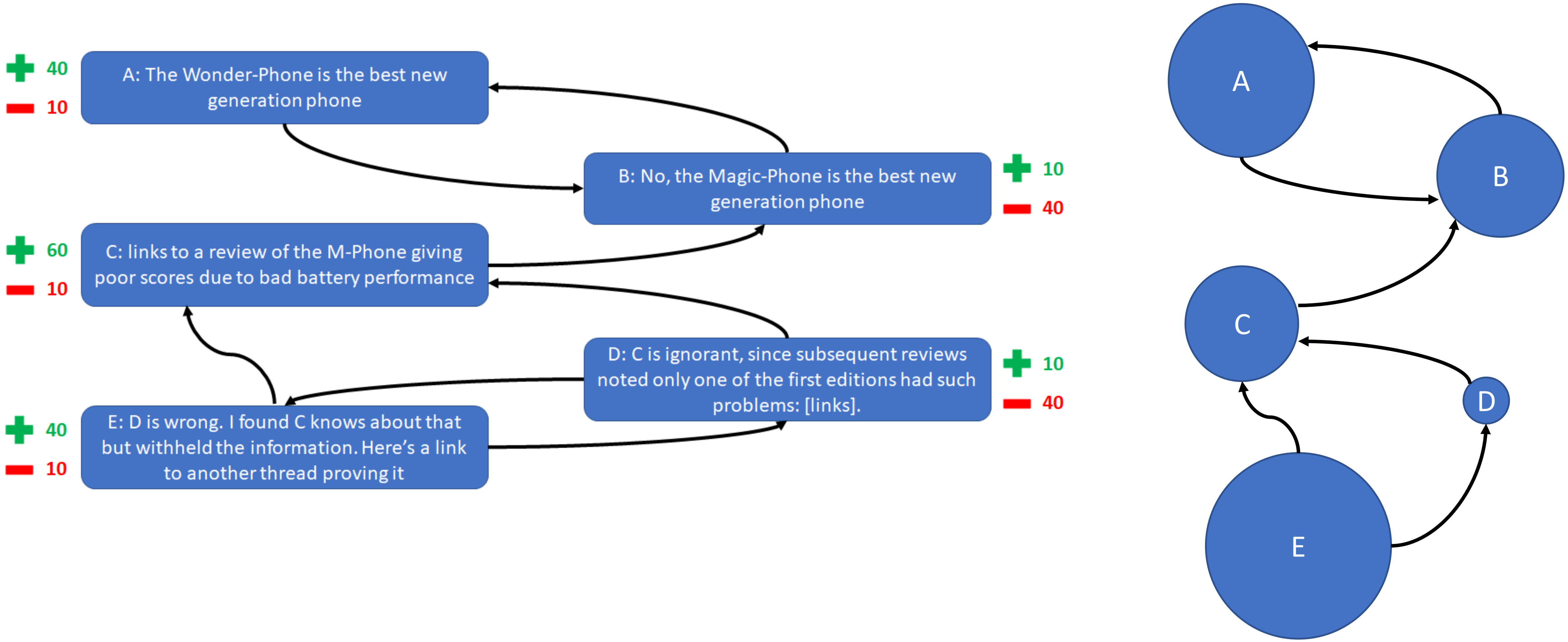

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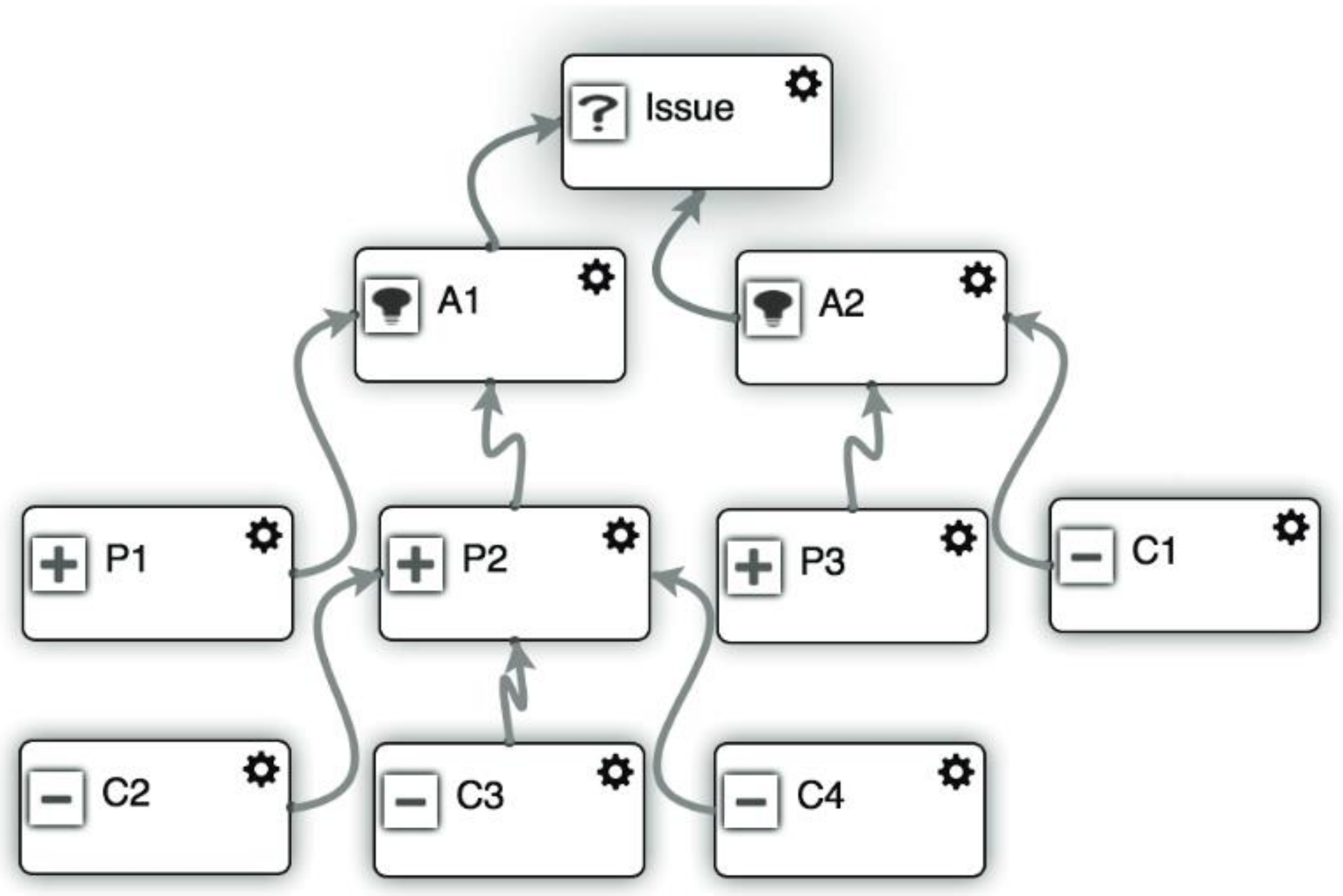
Decision Support (Rago et al. 2016)

Issue

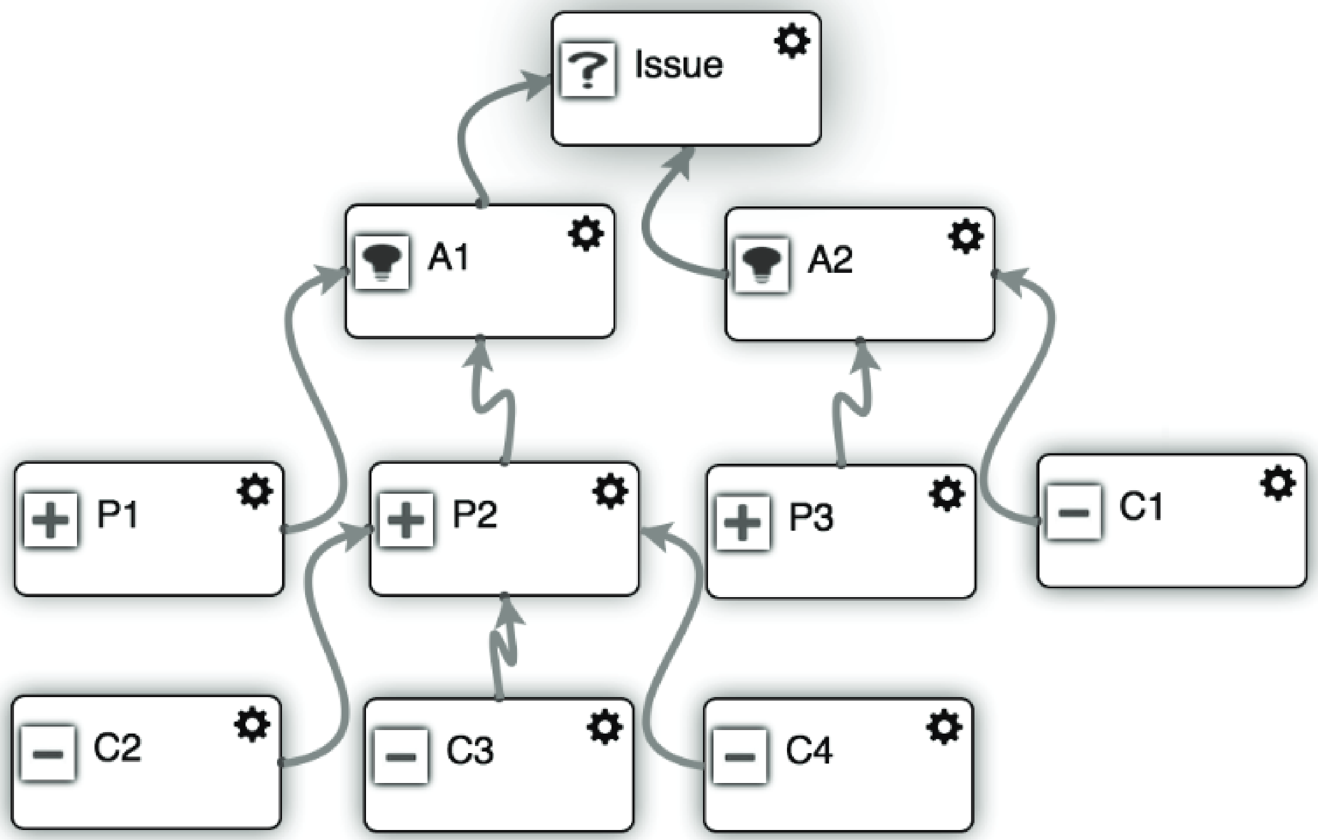
Alternatives

Pro and Con Arguments



Rago, A., Toni, F., Aurisicchio, M., & Baroni, P. Discontinuity-free decision support with quantitative argumentation debates (2016). In Fifteenth International Conference on the Principles of Knowledge Representation and Reasoning (KR): 63-73.

Decision Support (Rago et al. 2016)



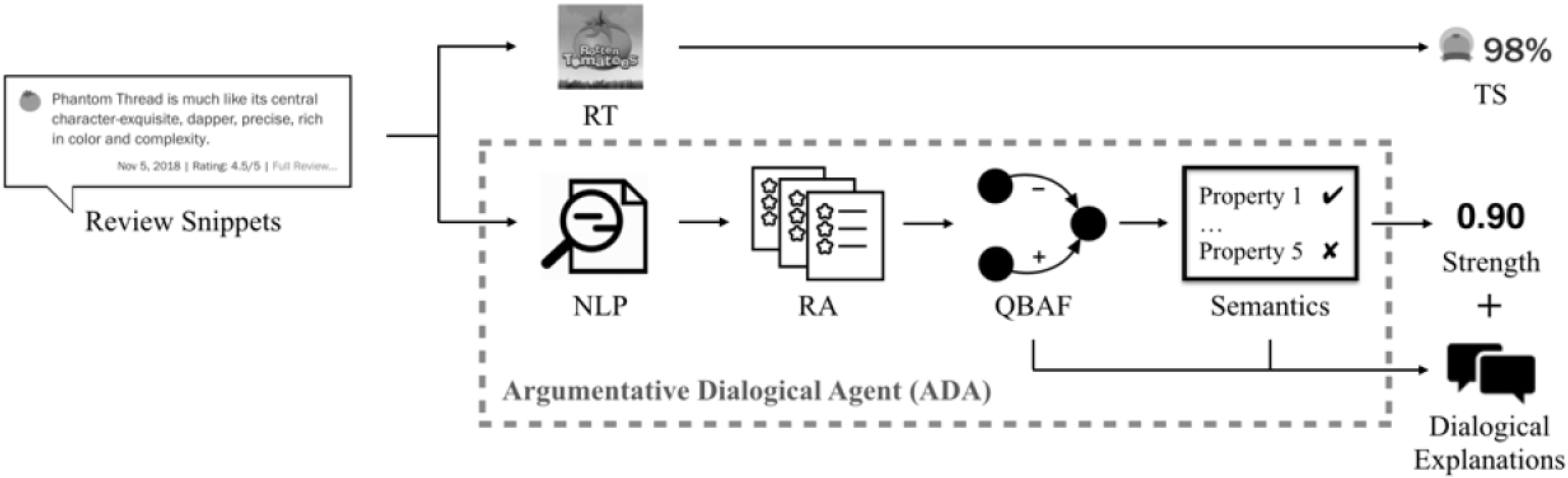
Issue: How to spend council's budget?

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.

Rago, A., Toni, F., Aurisicchio, M., & Baroni, P. Discontinuity-free decision support with quantitative argumentation debates (2016). In Fifteenth International Conference on the Principles of Knowledge Representation and Reasoning (KR): 63-73.

Explainable Review Aggregation (Cocarascu et al. 2019)



Cocarascu, O., Rago, A., & Toni, F. Extracting Dialogical Explanations for Review Aggregations with Argumentative Dialogical Agents (2019). In 18th International Conference on Autonomous Agents and MultiAgent Systems (AAMAS): 1261-1269.

From Reviews to BAGs

Pipeline

1. Extract argumentative phrases.
2. Associate phrases with features.
3. Compute sentiment of arguments.
4. Aggregate sentiments and derive attack/support relations and weights

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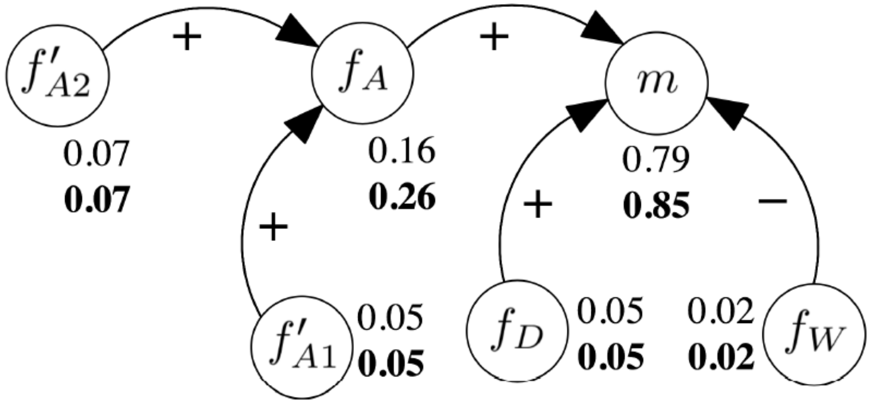

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Explainable Review Aggregation (Cocarascu et al. 2019)

$$r_a^+(\gamma) = \{\text{because (the) } \gamma \text{ was/were great}\};$$
$$r_a^-(\gamma) = \{\text{because (the) } \gamma \text{ was/were poor}\};$$
$$r_b^+(\gamma) = \{\text{although (the) } \gamma \text{ was/were great}\};$$
$$r_b^-(\gamma) = \{\text{although (the) } \gamma \text{ was/were poor}\};$$
$$r_a^+(\varnothing) = r_a^-(\varnothing) = r_b^+(\varnothing) = r_b^-(\varnothing) = \{\}.$$

Then, a *simple argumentation dialogue* is such that for any $\alpha \in \mathcal{A}$:

if $\alpha = m$ and $\sigma(\alpha) < 0.6$ and $\exists \beta \in \mathcal{L}^-(\alpha) \cup \mathcal{L}^+(\alpha)$ s.t. $\sigma(\beta) > 0$:

$\mathcal{Q}(\alpha) = \{\text{Why was } \alpha \text{ poorly rated?}\}$

$\mathcal{X}(\alpha) = \{\text{This movie was poorly rated}\} +$

$r_a^-(max(\mathcal{L}^-(m))) + r_b^+(max(\mathcal{L}^+(m)))$; else

if $\alpha = m$ and $\sigma(\alpha) \geq 0.6$ and $\exists \beta \in \mathcal{L}^-(\alpha) \cup \mathcal{L}^+(\alpha)$ s.t. $\sigma(\beta) > 0$:

$\mathcal{Q}(\alpha) = \{\text{Why was } \alpha \text{ highly rated?}\}$

$\mathcal{X}(\alpha) = \{\text{This movie was highly rated}\} +$

$r_a^+(max(\mathcal{L}^+(m))) + r_b^-(max(\mathcal{L}^-(m)))$; else

if $\alpha \in \mathcal{F}$ and $\mathcal{V}^+(\alpha) < \mathcal{V}^-(\alpha)$ and $\exists \beta \in \mathcal{L}^-(\alpha) \cup \mathcal{L}^+(\alpha)$ s.t. $\sigma(\beta) > 0$:

$\mathcal{Q}(\alpha) = \{\text{Why was/were (the) } \alpha \text{ considered to be poor?}\}$

$\mathcal{X}(\alpha) = \{\text{(The) } \alpha \text{ was/were considered to be poor}\} +$

$r_a^-(max(\mathcal{L}^-(m))) + r_b^+(max(\mathcal{L}^+(m)))$; else

if $\alpha \in \mathcal{F}$ and $\mathcal{V}^+(\alpha) \geq \mathcal{V}^-(\alpha)$ and $\exists \beta \in \mathcal{L}^-(\alpha) \cup \mathcal{L}^+(\alpha)$ s.t. $\sigma(\beta) > 0$:

$\mathcal{Q}(\alpha) = \{\text{Why was/were (the) } \alpha \text{ considered to be great?}\}$

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$r_a^+(max(\mathcal{L}^+(m))) + r_b^-(max(\mathcal{L}^-(m)))$; else

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$\mathcal{Q}(\alpha) = \{\text{What did critics say about (the) } \alpha \text{ being poor?}\}$

$\mathcal{X}(\alpha) = \{[p \text{ from } c \in \mathcal{C} \text{ constituting } \mathcal{V}(c, \alpha) = -]\}$; else

if $\mathcal{V}^+(\alpha) \geq \mathcal{V}^-(\alpha)$ and $\nexists \beta \in \mathcal{L}^-(\alpha) \cup \mathcal{L}^+(\alpha)$ s.t. $\sigma(\beta) > 0$:

$\mathcal{Q}(\alpha) = \{\text{What did critics say about (the) } \alpha \text{ being great?}\}$

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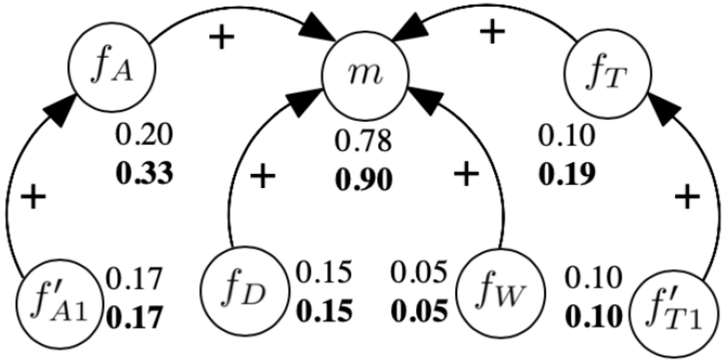

user: *Why was Phantom Thread highly rated?*
ADA: *This movie was highly rated because the acting was great.*
user: *Why was the acting considered to be great?*
ADA: *The acting was considered to be great because Daniel Day-Lewis was great.*
user: *What did critics say about Daniel Day-Lewis being great?*
ADA: *"...Daniel Day-Lewis remains our greatest actor..."*

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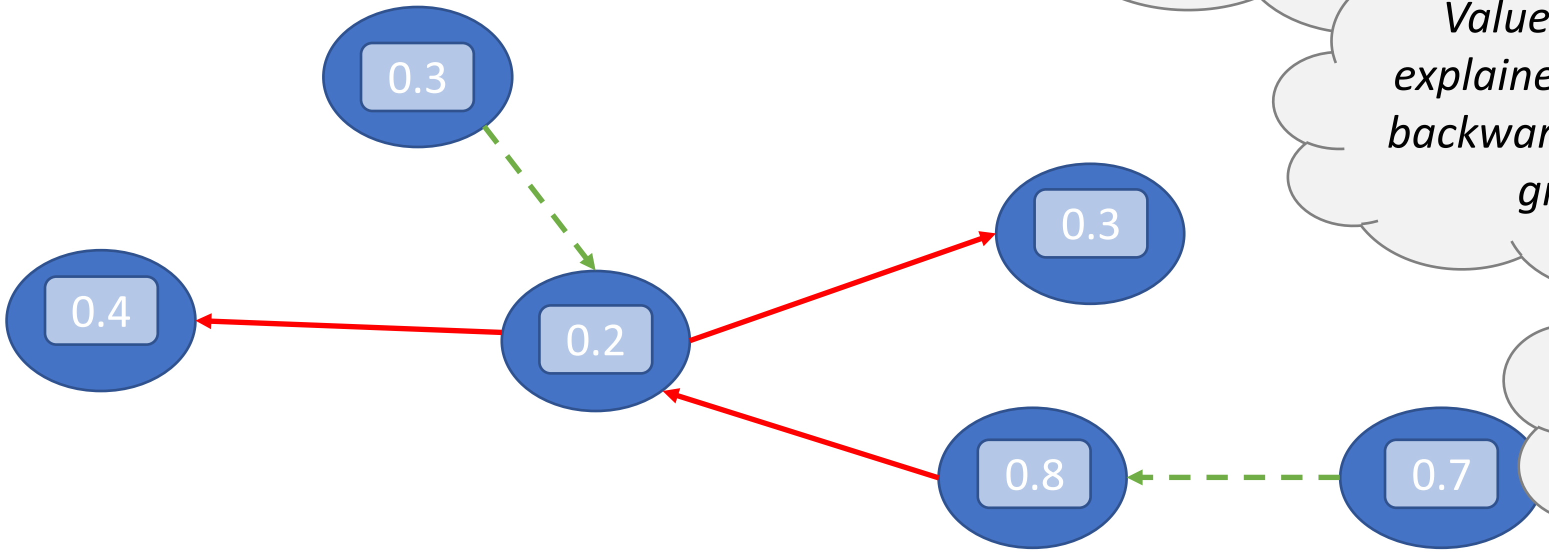
Summary

Quantitative AAFs assign numerical values (belief, strength) to arguments

Values can be explained by going backwards through graph

Rules can be used to generate simple automated explanation dialogues



Summary

- Probabilistic Epistemic Argumentation
- Evaluation: probabilities
- Complexity: (polynomial)
- Model
  - Bipolar Argumentation Graph
  - Semantical Constraints
- Implementation *https://sourceforge.net/projects/probabble/*

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- Gradual Bipolar Argumentation
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Probabilistic Epistemic Argumentation

Semantics and Computation

Probabilistic Epistemic Argumentation

- Ingredients
  - BAG
  - Semantical Constraints like
    - Founded: If A unattacked, then $P(A) \geq 0.5$
    - Coherence: If A attacks B, then $P(B) \leq 1 - P(A)$
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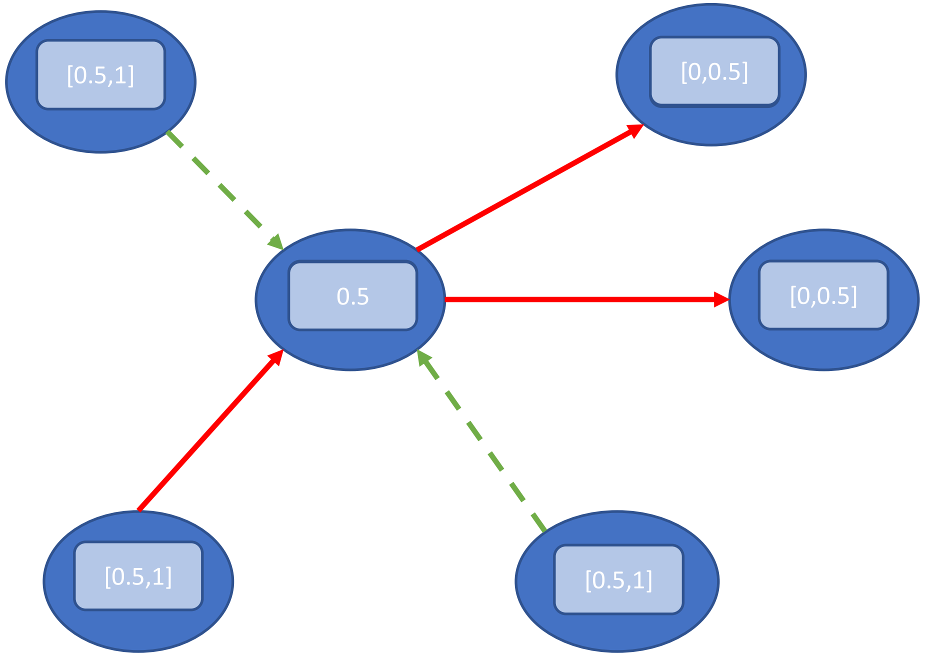
    - …



- If all constraints are „linear atomic“, solvable in polynomial time *[2]*

$$\sum_{i=1}^{n} c_i \cdot P(A_i) \leq c_0$$

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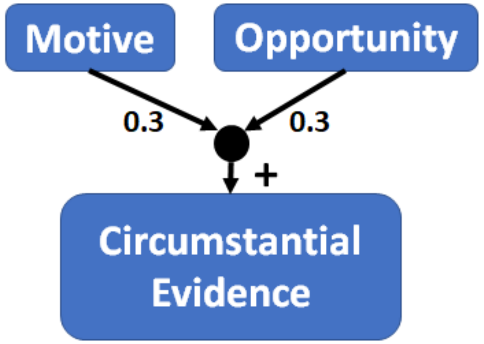
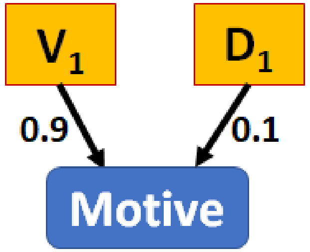
Some Other Linear Atomic Constraints



$$P(CE) \geq 0.3 \cdot P(M) + 0.3 \cdot P(O)$$
$$\equiv$$
$$0.3 \cdot P(M) + 0.3 \cdot P(O) \ - P(CE) \leq 0$$



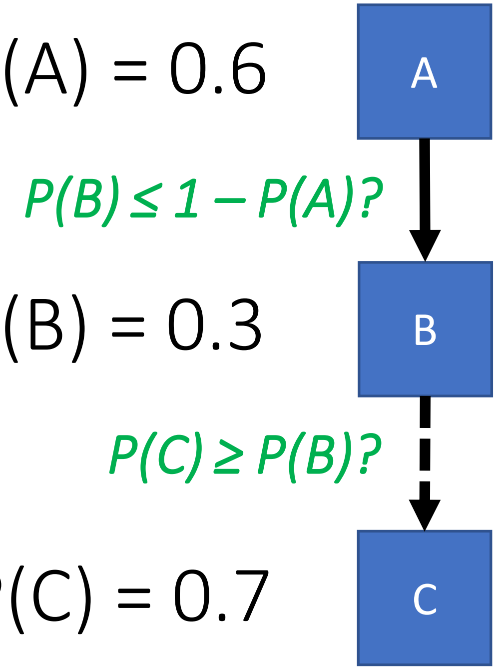
$$P(M) \geq \max\big(0.9 \cdot P(V_1), 0.9 \cdot P(D_1)\big)$$
$$\equiv$$
$$0.9 \cdot P(V_1) \ - P(M) \ \leq 0$$
$$0.9 \cdot P(D_1) \ - P(M) \ \leq 0$$

Epistemic States (Probability Functions)

P(A) = 0.6

P(B) = 0.3

P(C) = 0.7



A	B	C	P(A,B,C)
0	0	0	0
0	0	1	0.1
0	1	0	0
0	1	1	0.3
1	0	0	0.3
1	0	1	0.3
1	1	0	0
1	1	1	0

Consistent constraints are usually satisfied by an infinite number of probability functions

Reasoning Problems

- *SATISFIABILITY*:
  - Given BAG with Semantical Constraints
  - Is there a probability function that satisfies all constraints?

- ENTAILMENT
  - Given BAG with satisfiable Semantical Constraints and argument A
  - Compute tight lower and upper bounds for P(A)

- If all constraints are „linear atomic“, both problems can be solved efficiently [2]

[2] Potyka, N. (2019). A polynomial-time fragment of epistemic probabilistic argumentation. *International Journal of Approximate Reasoning*, *115*, 265-289.

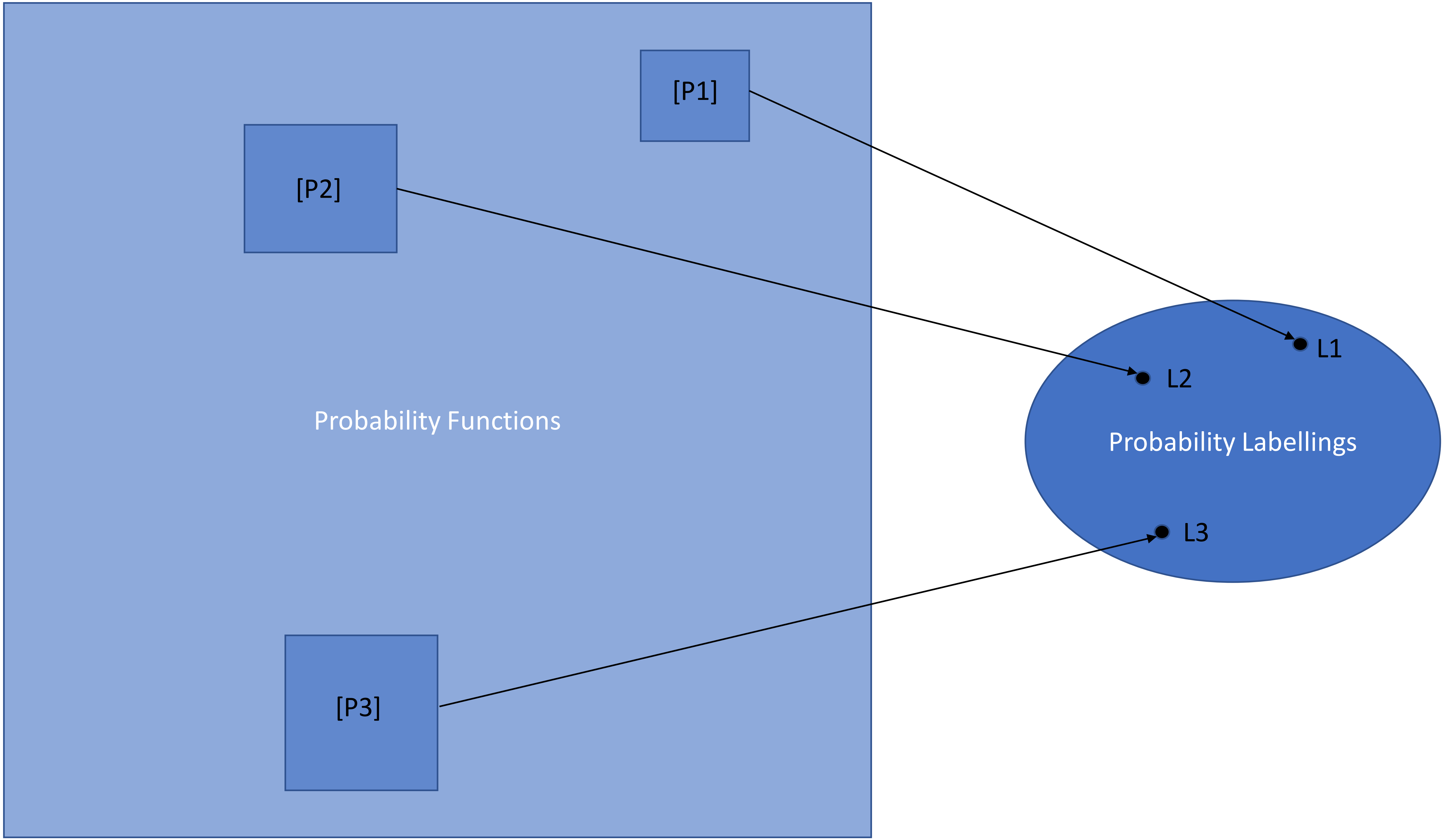
Probability Labellings

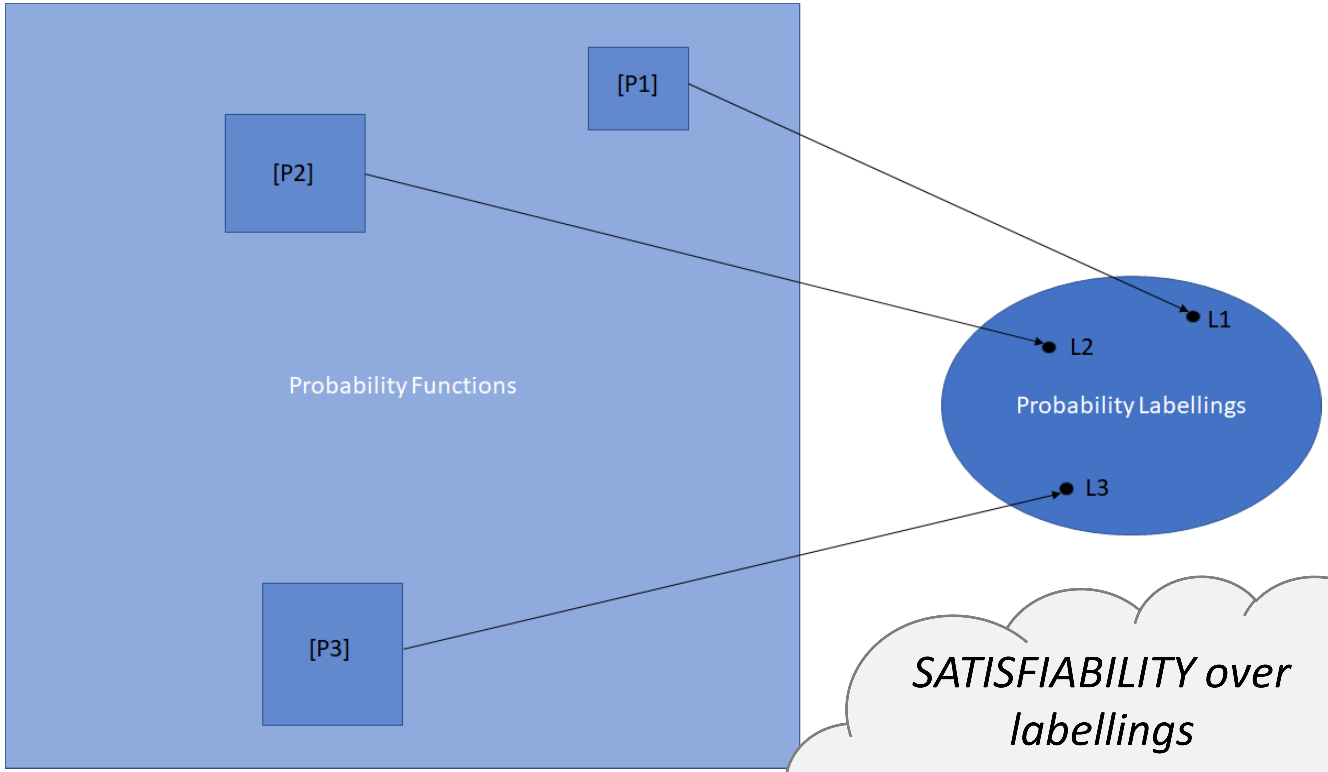
A	B	C	P(A,B,C)
0	0	0	0
0	0	1	0.1
0	1	0	0
0	1	1	0.3
1	0	0	0.3
1	0	1	0.3
1	1	0	0
1	1	1	0

Arg	L(Arg)
A	0.6
B	0.3
C	0.7

A	B	C	P(A,B,C)
0	0	0	0
0	0	1	0.4
0	1	0	0
0	1	1	0
1	0	0	0.3
1	0	1	0
1	1	0	0
1	1	1	0.3

A	B	C	P(A,B,C)
0	0	0	0
0	0	1	0.25
0	1	0	0
0	1	1	0.15
1	0	0	0.3
1	0	1	0.15
1	1	0	0
1	1	1	0.15


[P1]
[P2]
Probability Functions
[P3]
L1
L2
Probability Labellings
L3



SATISFIABILITY over labellings = SATISFIABILITY over probability functions

ENTAILMENT over labellings = ENTAILMENT over probability functions

Lemma: The following statements are equivalent:

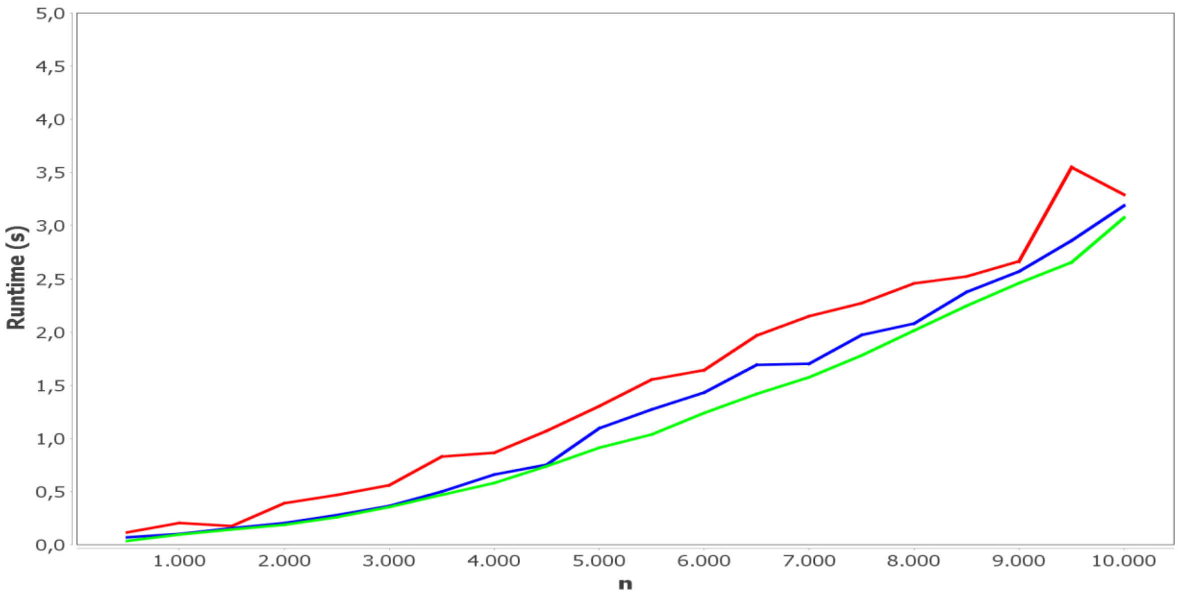
1. P satisifies a ***linear atomic constraint*** c.
2. All P’ in [P] satisify c.
3. L = r([P]) satisifies c.

[2] Potyka, N. (2019). A polynomial-time fragment of epistemic probabilistic argumentation. *International Journal of Approximate Reasoning*, *115*, 265-289.

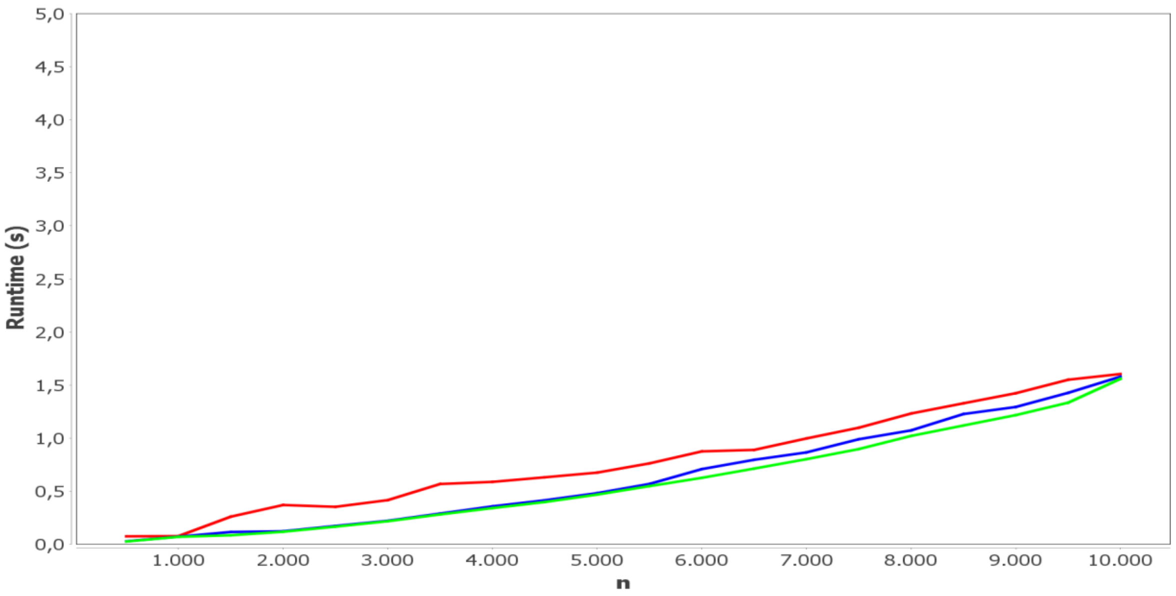
Solving Reasoning Problems

SATISFIABILITY and ENTAILMENT problem can be encoded as LPs

- Interior-point methods give polynomial worst-case bound
- Simplex algorithm is often faster in practice (even though worst-case runtime is exponential)



Min, Avg, Max Runtime for SATISFIABILITY over random satisfiable BAGs.



Min, Avg, Max Runtime for SATISFIABILITY over random unsatisfiable BAGs.

Potyka, N. (2019). A polynomial-time fragment of epistemic probabilistic argumentation. *International Journal of Approximate Reasoning*, *115*, 265-289.

Adding Expressiveness

If $P \neq NP$, we lose polynomial runtime guarantees when allowing

- Disjunctions of arguments $P(A \vee B)$
- Conjunctions of arguments $P(A \wedge B)$

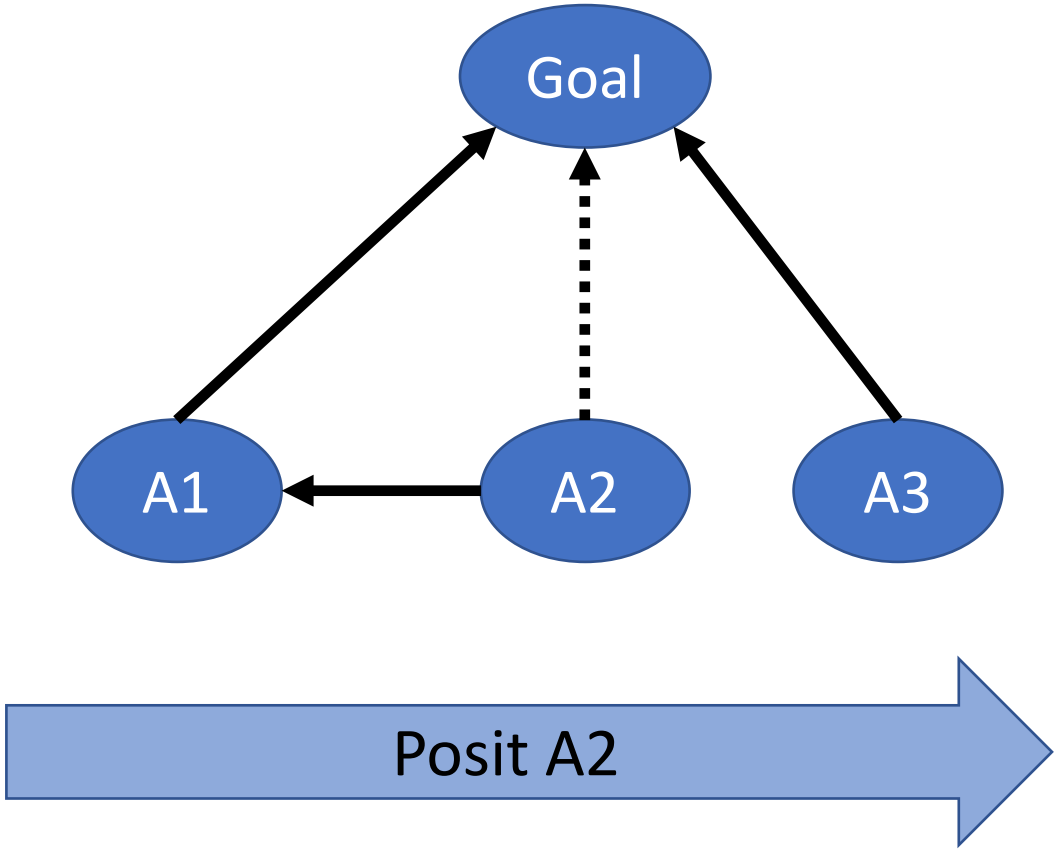
Some problems remain tractable when applying the principle of maximum entropy

- *but results in strong independency assumptions*
- *constraints like Coherence and S-Coherence can still give some meaningful guarantees for relationships between arguments*

Potyka, N. (2019). A polynomial-time fragment of epistemic probabilistic argumentation. *International Journal of Approximate Reasoning*, *115*, 265-289.

Updates Revisited

Argument	Belief
A1	0.8
A2	0.1
A3	0.2
Goal	0.2



Argument	Belief
A1	0.3
A2	0.7
A3	0.2
Goal	0.7

Epistemic Update Operators

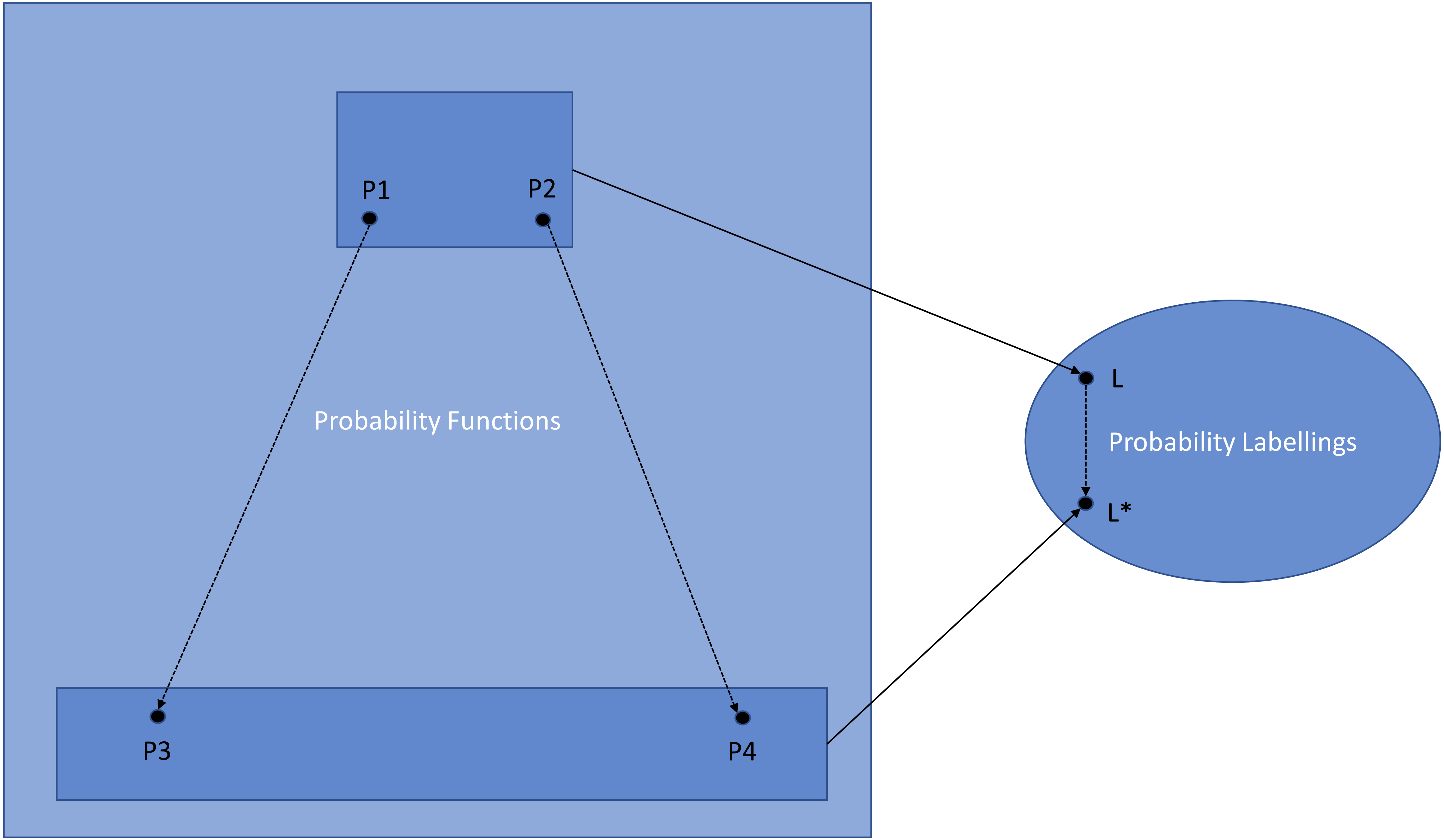
Definition 1 (Epistemic Update Operator). *An* epistemic update operator *is a function* $\mathcal{U} : \mathcal{P}_\mathcal{A} \times \mathcal{C}_\mathcal{A} \rightarrow \mathcal{P}_\mathcal{A} \cup \{\bot\}$ *that satisfies the following properties:*

- ***Success:*** *If* $C \subseteq \mathcal{C}_\mathcal{A}$ *is satisfiable, then* $\mathcal{U}(P, C) \in \mathrm{Sat}_\Pi(C)$.
- ***Failure:*** *If* $C \subseteq \mathcal{C}_\mathcal{A}$ *is not satisfiable, then* $\mathcal{U}(P, C) = \bot$.
- ***Representation Invariance:*** *If* $C_1 \equiv C_2$*, then* $\mathcal{U}(P, C_1) = \mathcal{U}(P, C_2)$.
- ***Idempotence:*** *If* $C \subseteq \mathcal{C}_\mathcal{A}$ *is satisfiable, then* $\mathcal{U}(\mathcal{U}(P, C), C) = \mathcal{U}(P, C)$.

Update operators can be defined by minimizing distance between prior and new epistemic state

$$P_1 \xrightarrow{\mathcal{U}^2_{\mathrm{At}}(P_1, C)} P_2$$

Hunter, A., Polberg, S., & Potyka, N. (2018). Updating belief in arguments in epistemic graphs. ECSQARU 2018.


P1
P2
Probability Functions
P3
P4
L
Probability Labellings
L*

Probability Functions

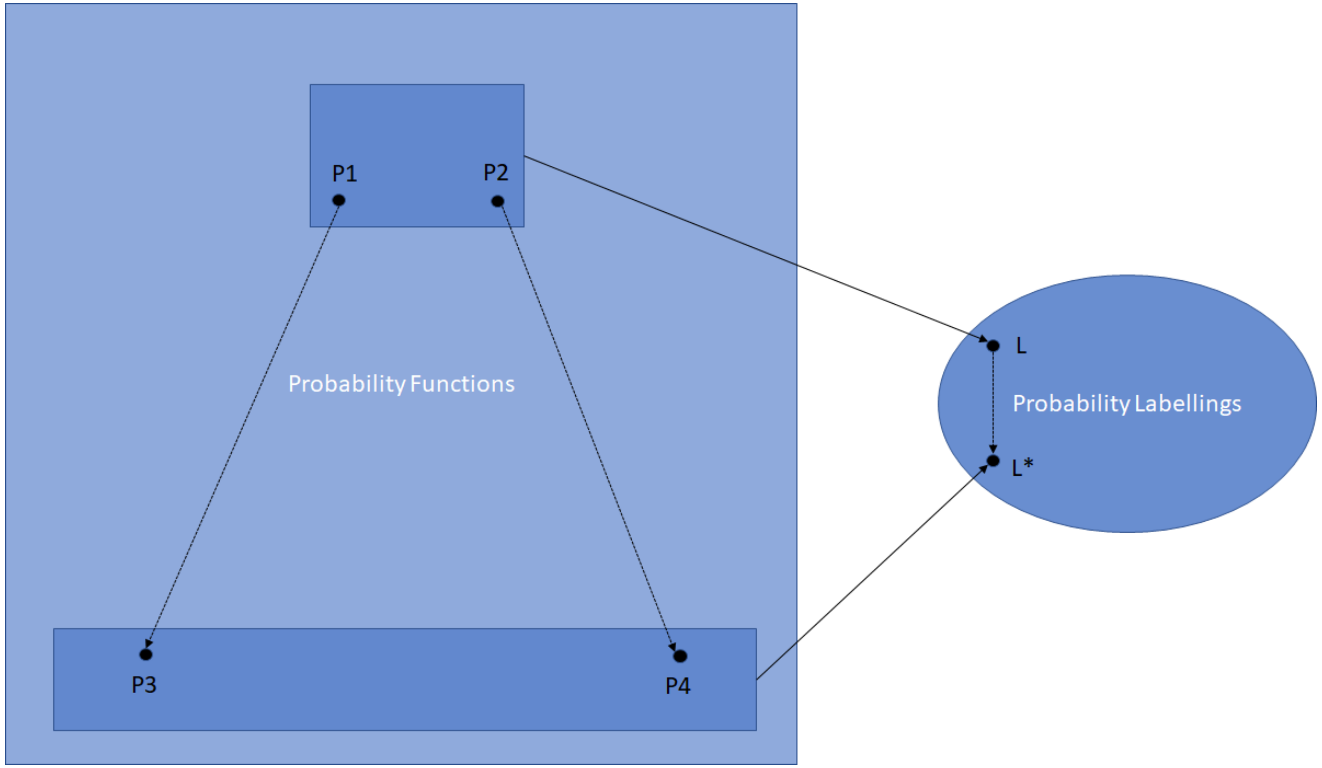
Probability Labellings

$\mathcal{U}^2_{\mathrm{At}}(P, C)$

$LU^2_{\lambda}(L, C)$

1. Minimize ***atomic LS distance*** to P
   (solution may not be unique)
2. Minimize ***LS distance*** to P
   (solution is unique)

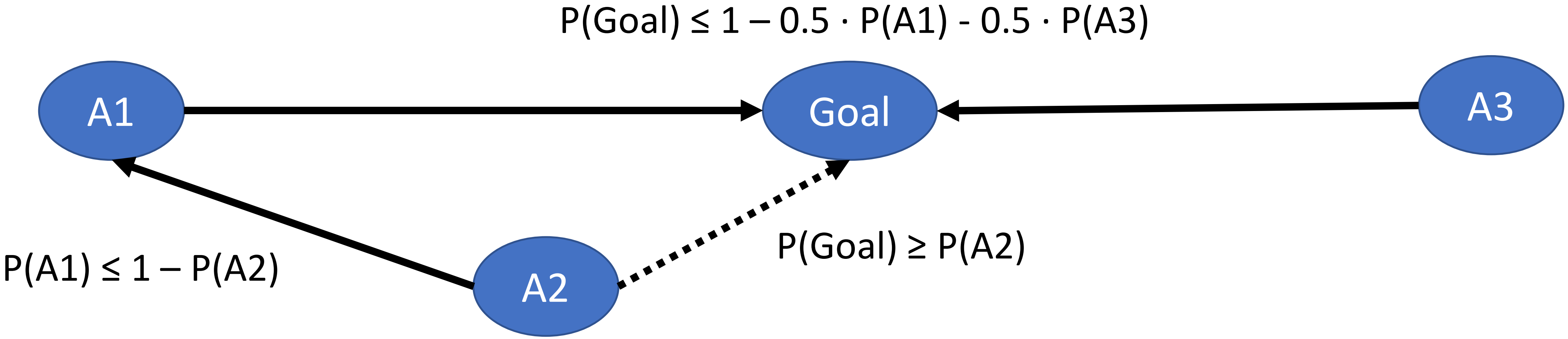
Minimize ***LS distance*** to L
(solution is unique)



Theorem 1. *Let $C \subset \mathcal{C}_{\mathcal{A}}$ be a finite and satisfiable set of linear atomic constraints and let $L \in \mathcal{L}_{\mathcal{A}}$. Then $LU^2_{\lambda}(L, C) = L^*$ is well-defined and can be computed in polynomial time. Furthermore, $L^* = r([\mathcal{U}^2_{\mathrm{At}}(P, C)])$ for all $P \in r^{-1}(L)$.*

Hunter, A., Polberg, S., & Potyka, N. (2018). Updating belief in arguments in epistemic graphs. ECSQARU 2018.

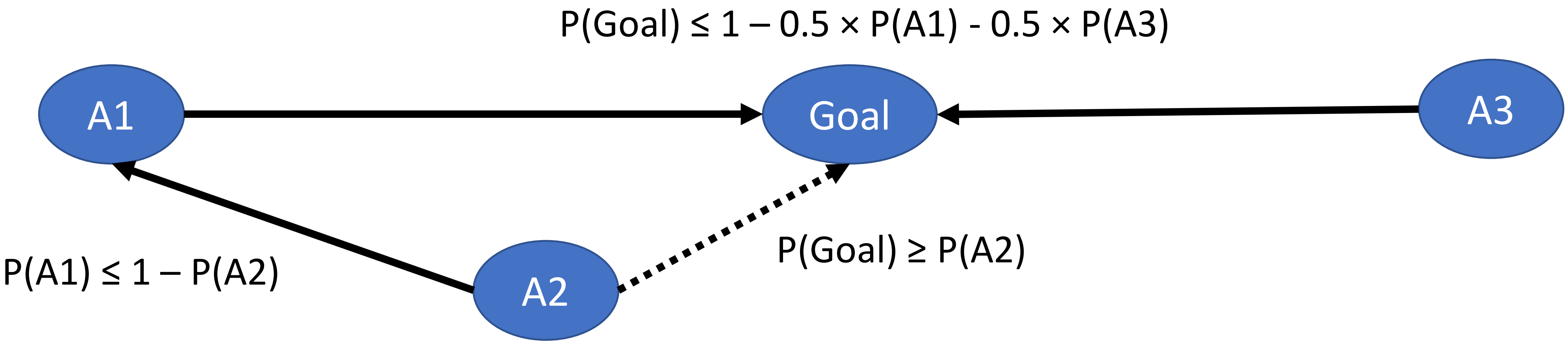
Argument	Belief
A1	0.8
A2	0.1
A3	0.2
Goal	0.2



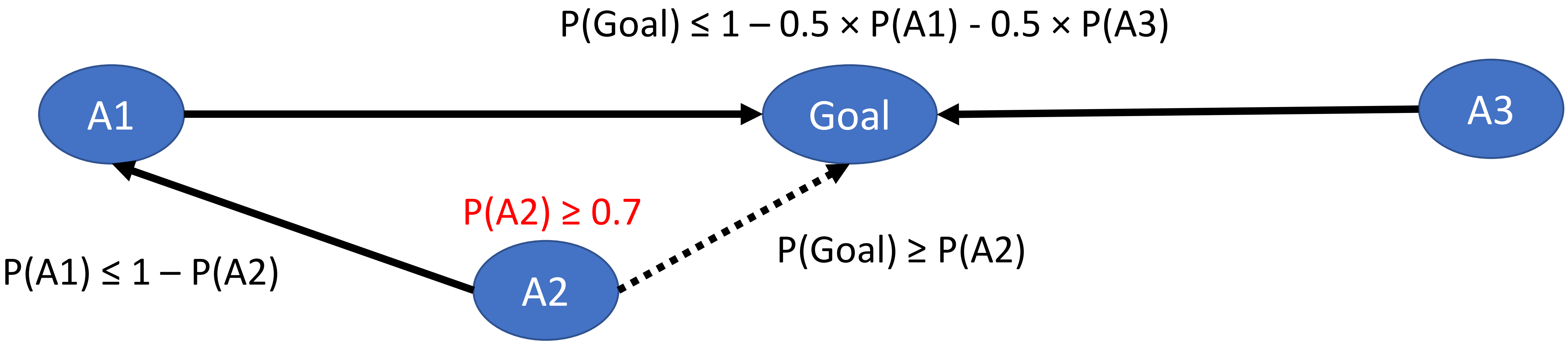
Argument	Belief
A1	0.8
A2	0.1
A3	0.2
Goal	0.2

Do you agree that A2?

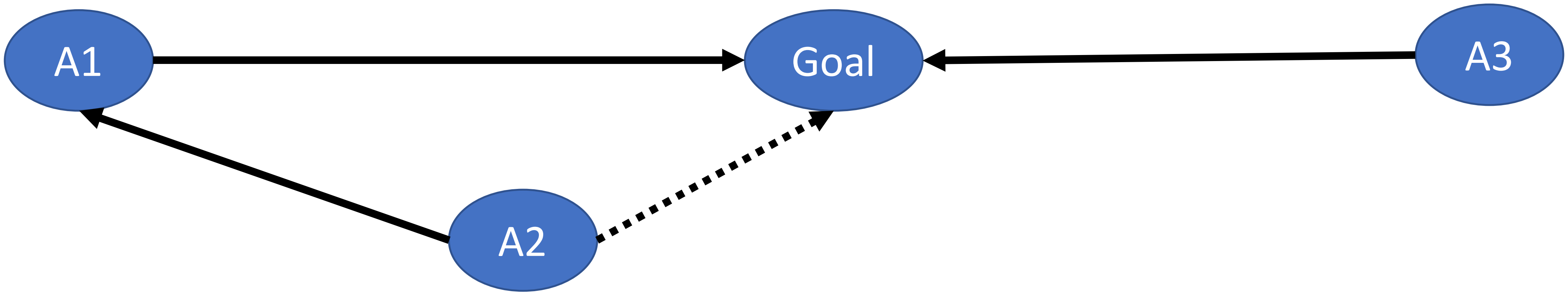
Strongly Agree	$P(A2) \geq 0.9$
Agree	$P(A2) \geq 0.7$
Indifferent	
Disagree	$P(A2) \leq 0.3$
Strongly Disagree	$P(A2) \leq 0.1$



Argument	Belief
A1	0.3
A2	0.7
A3	0.2
Goal	0.7



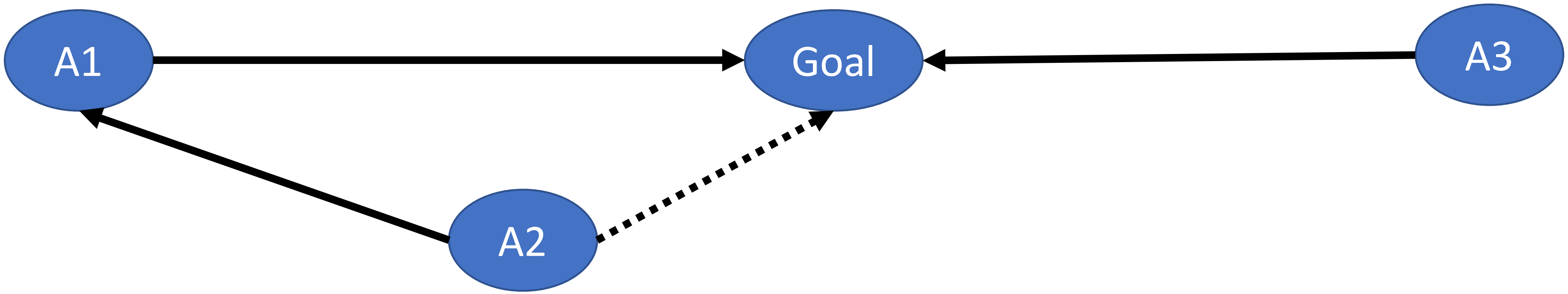
Argument	Belief
A1	0.8
A2	0.1
A3	0.2
Goal	0.2



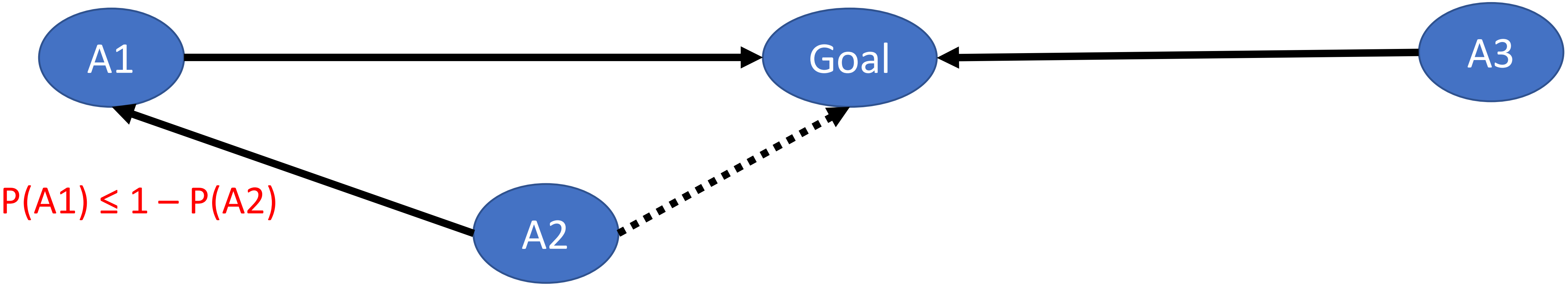
Argument	Belief
A1	0.8
A2	0.1
A3	0.2
Goal	0.2

Do you agree that if A2 then not A1?

- **Strongly Agree** — $P(A1) \leq 1 - P(A2)$
- Agree — $P(A1) \leq 1 - 0.5 \cdot P(A2)$
- Indifferent
- Disagree
- Strongly Disagree

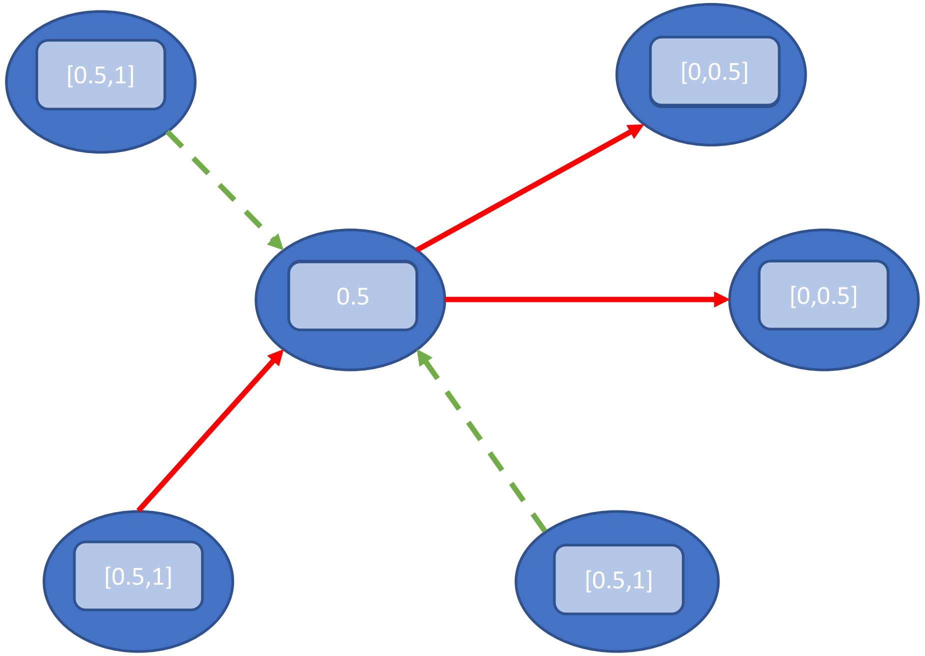


Argument	Belief
A1	0.8
A2	0.1
A3	0.2
Goal	0.2



Probabilistic Epistemic Argumentation

- Ingredients
  - BAG
  - Semantical Constraints like
    - Founded: If A unattacked, then $P(A) \geq 0.5$
    - Coherence: If A attacks B, then $P(B) \leq 1 - P(A)$
    - S-Coherence: If A supports B, then $P(\mathrm{A}) \leq P(\mathrm{B})$
    - …



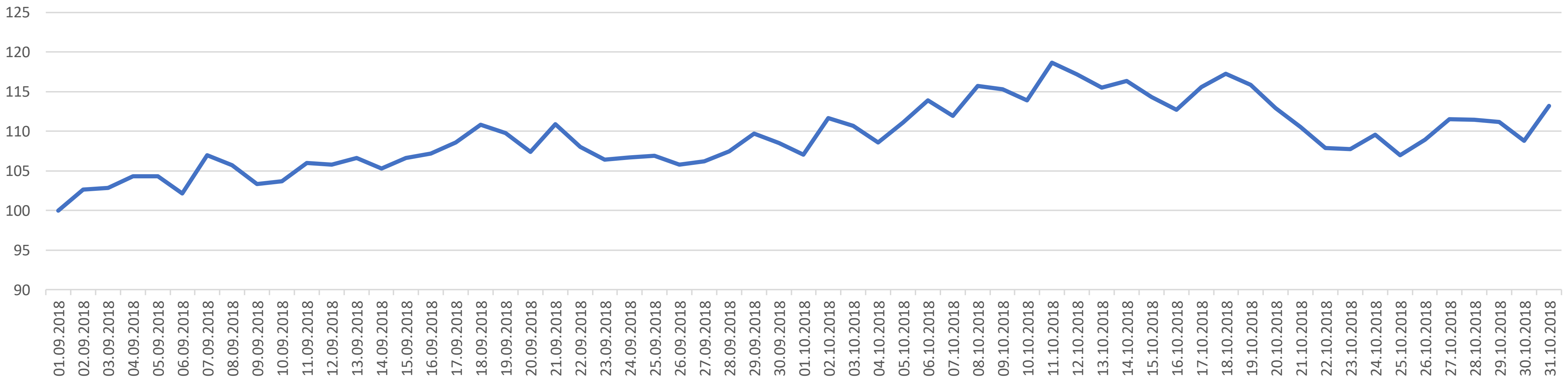
- If all constraints are „linear atomic“, solvable in polynomial time *[2]*

$$\sum_{i=1}^{n} c_i \cdot P(A_i) \leq c_0$$

[2] Potyka, N. (2019). A polynomial-time fragment of epistemic probabilistic argumentation. *International Journal of Approximate Reasoning*, *115*, 265-289.

Gradual Bipolar Argumentation

Semantics


125
120
115
110
105
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95
90
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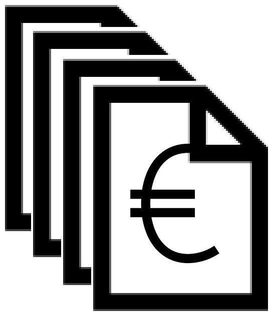
29.10.2018
30.10.2018
31.10.2018

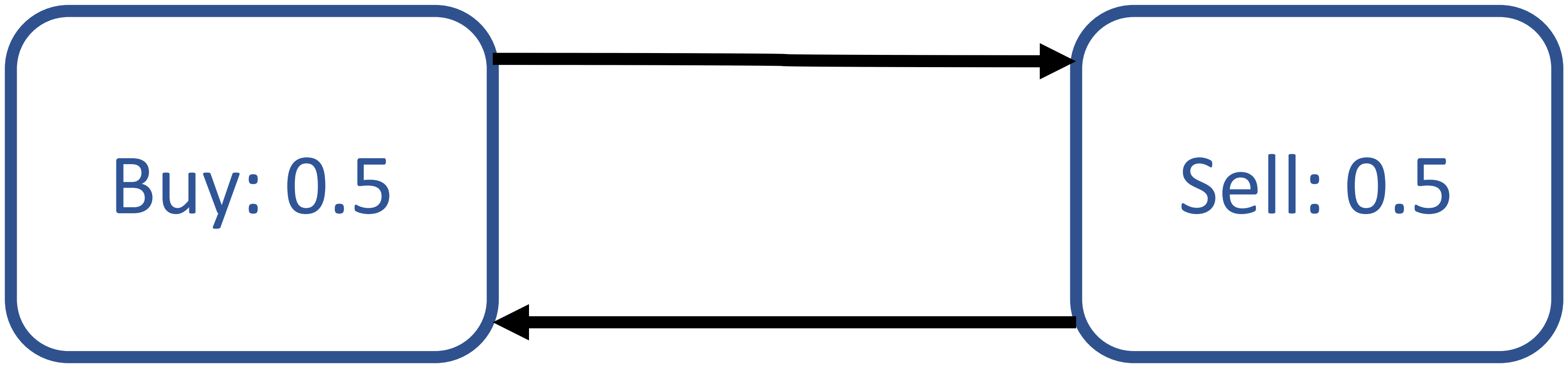
Buy?

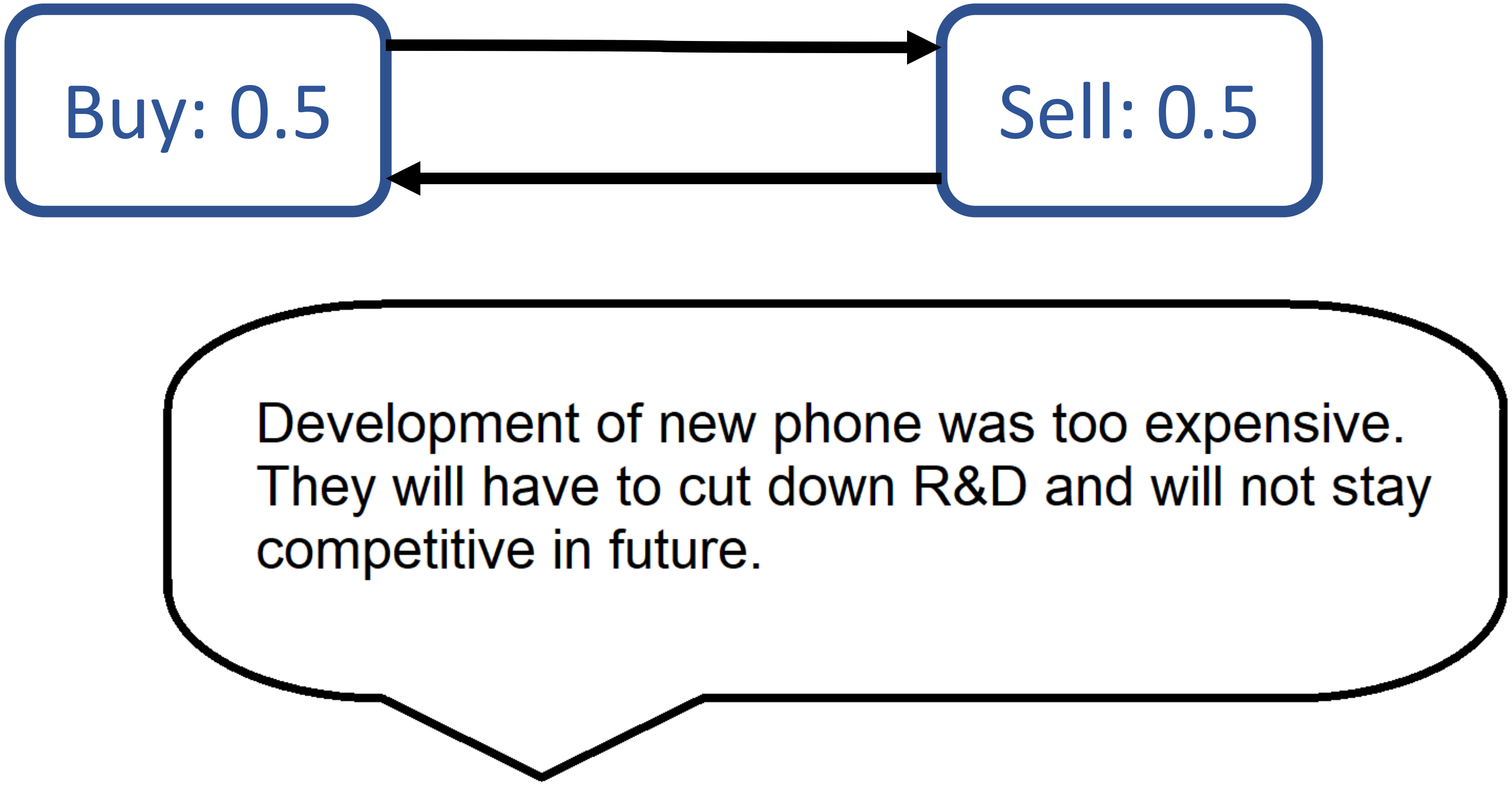


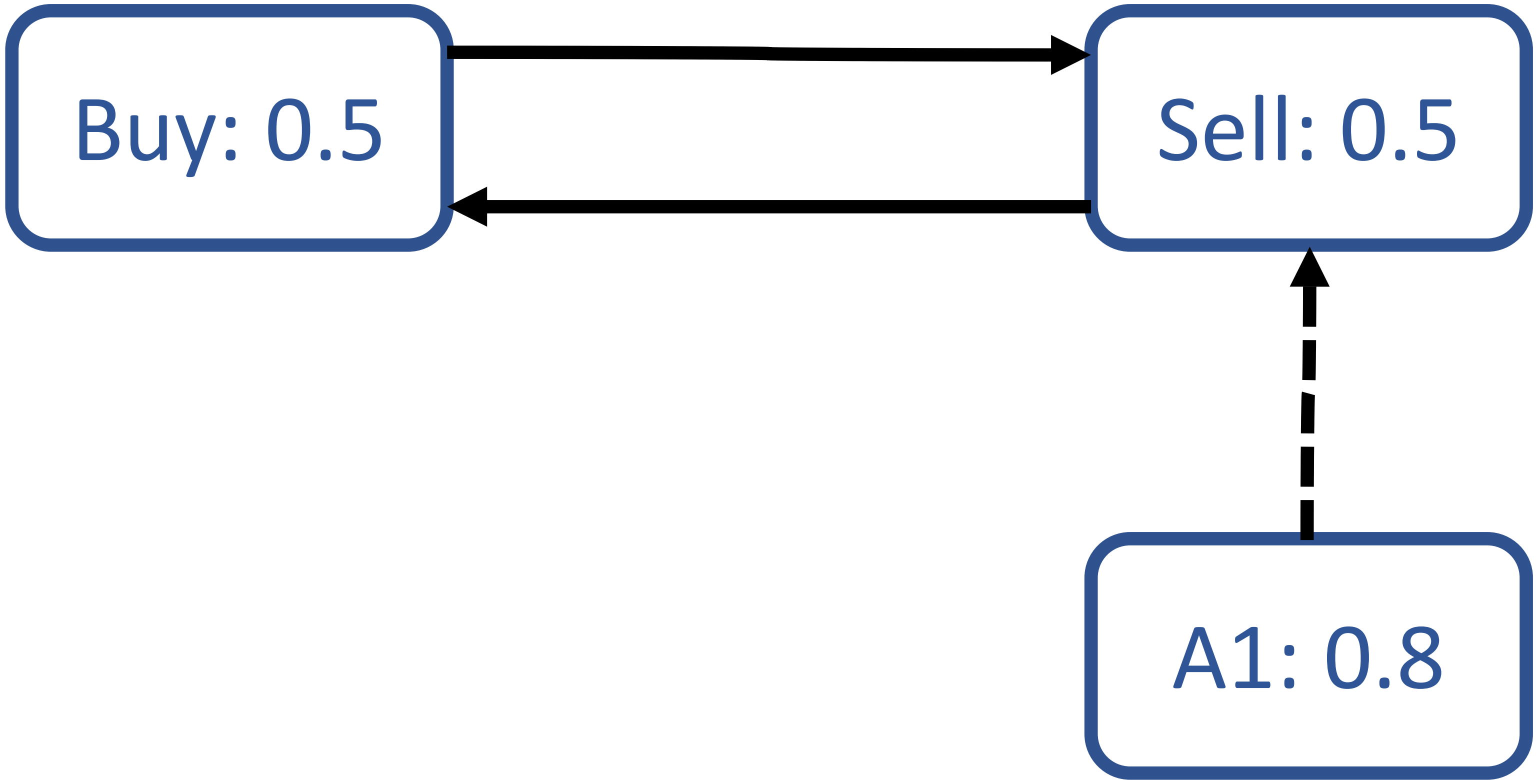
Sell?

Buy: 0.5

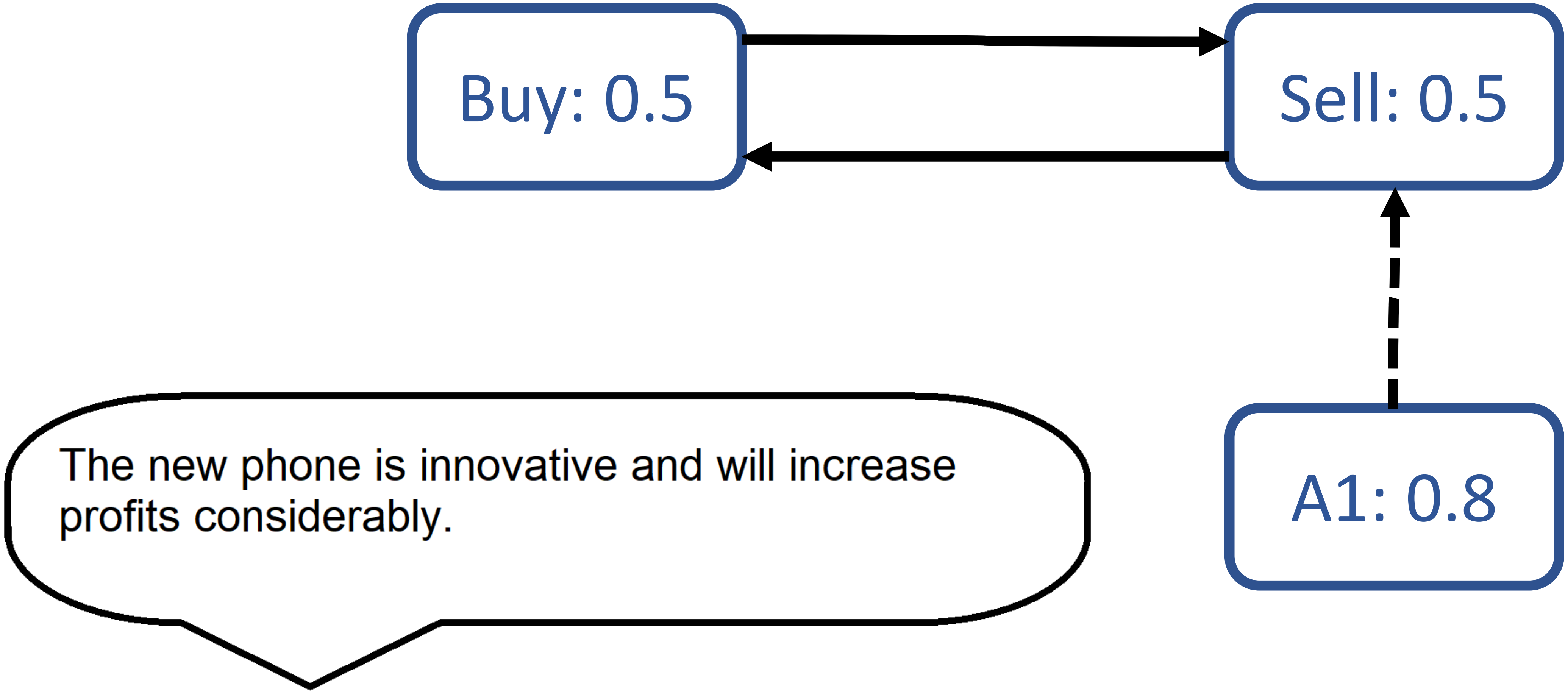
Sell: 0.5

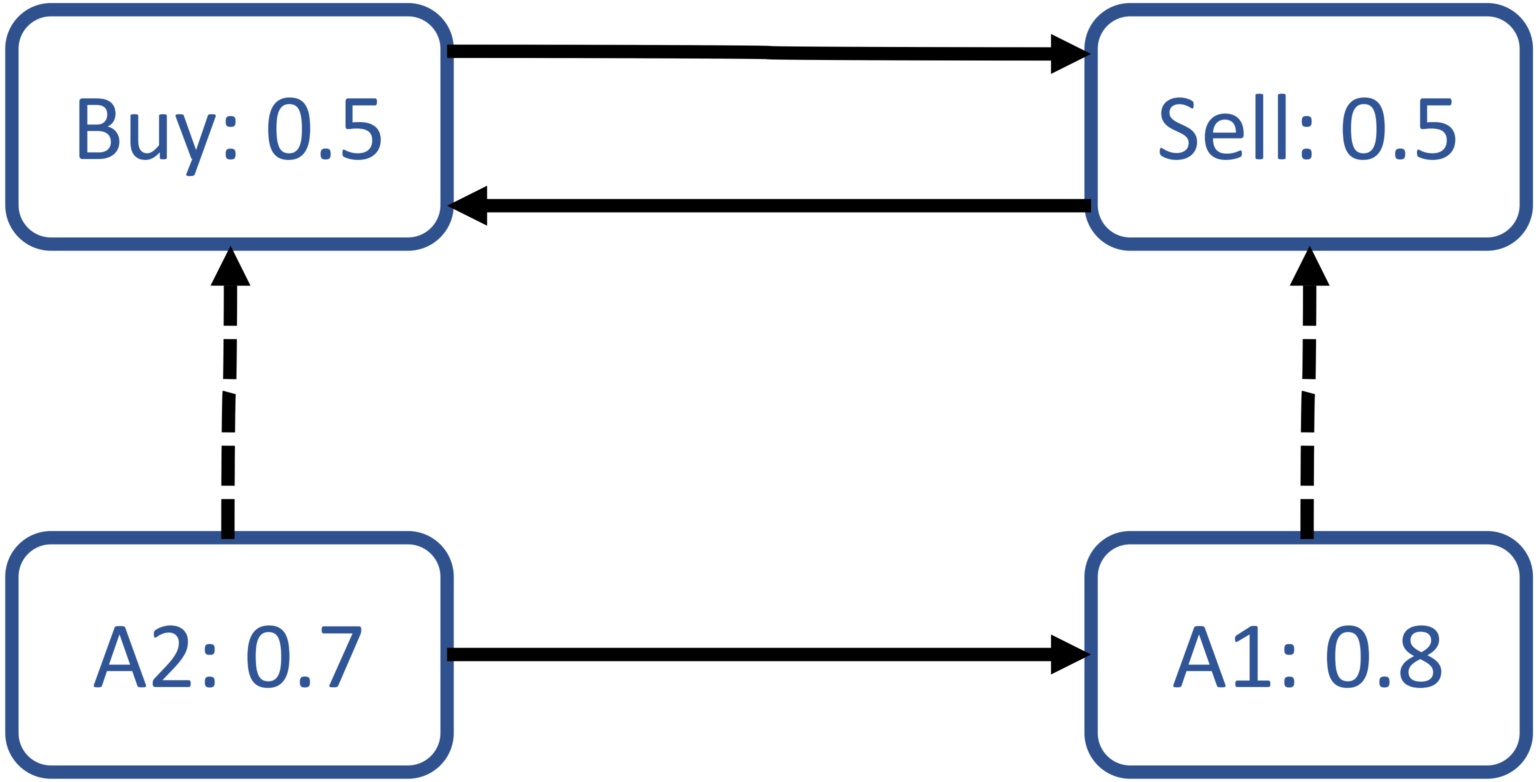

Buy: 0.5
Sell: 0.5


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.

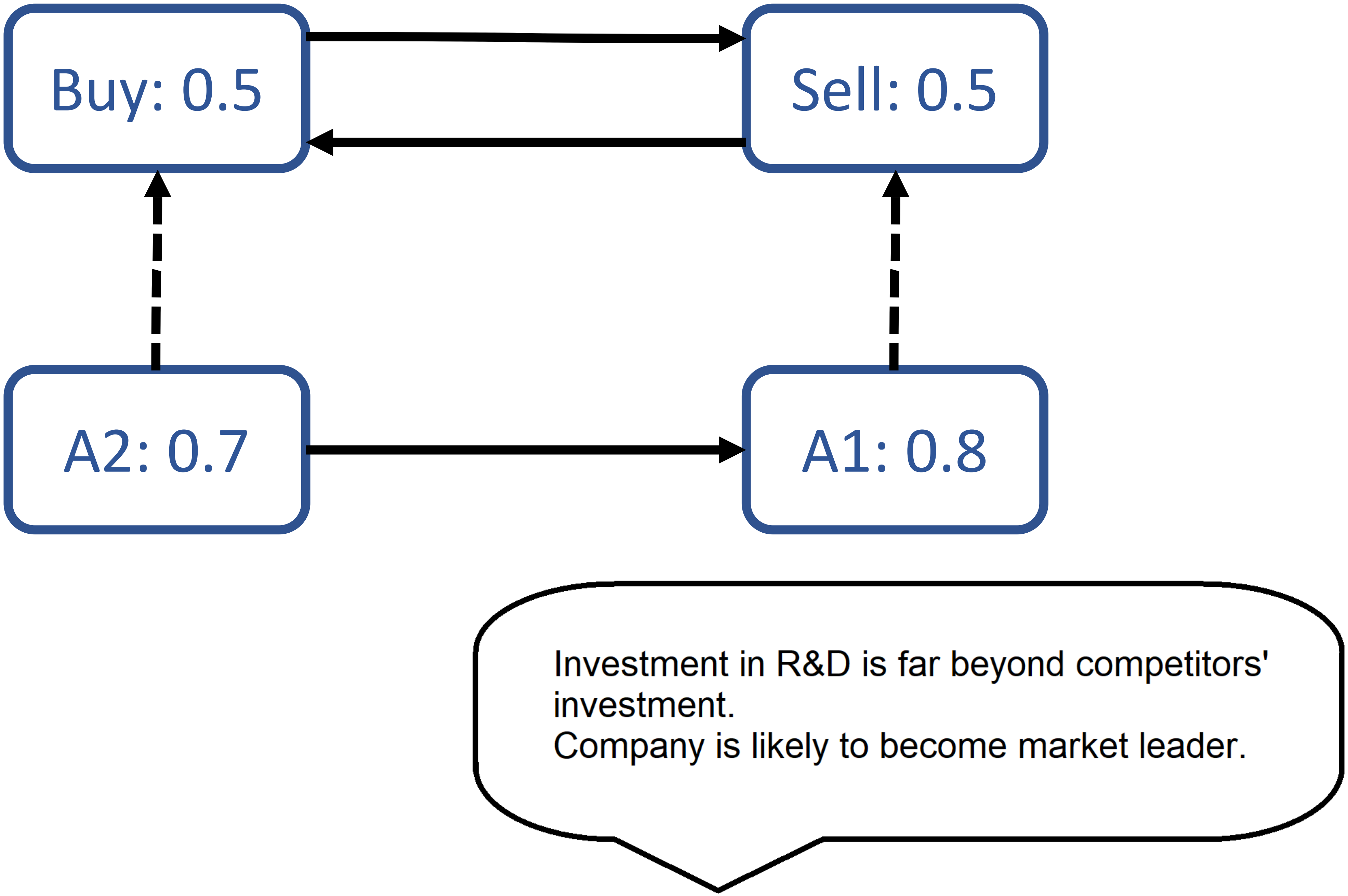


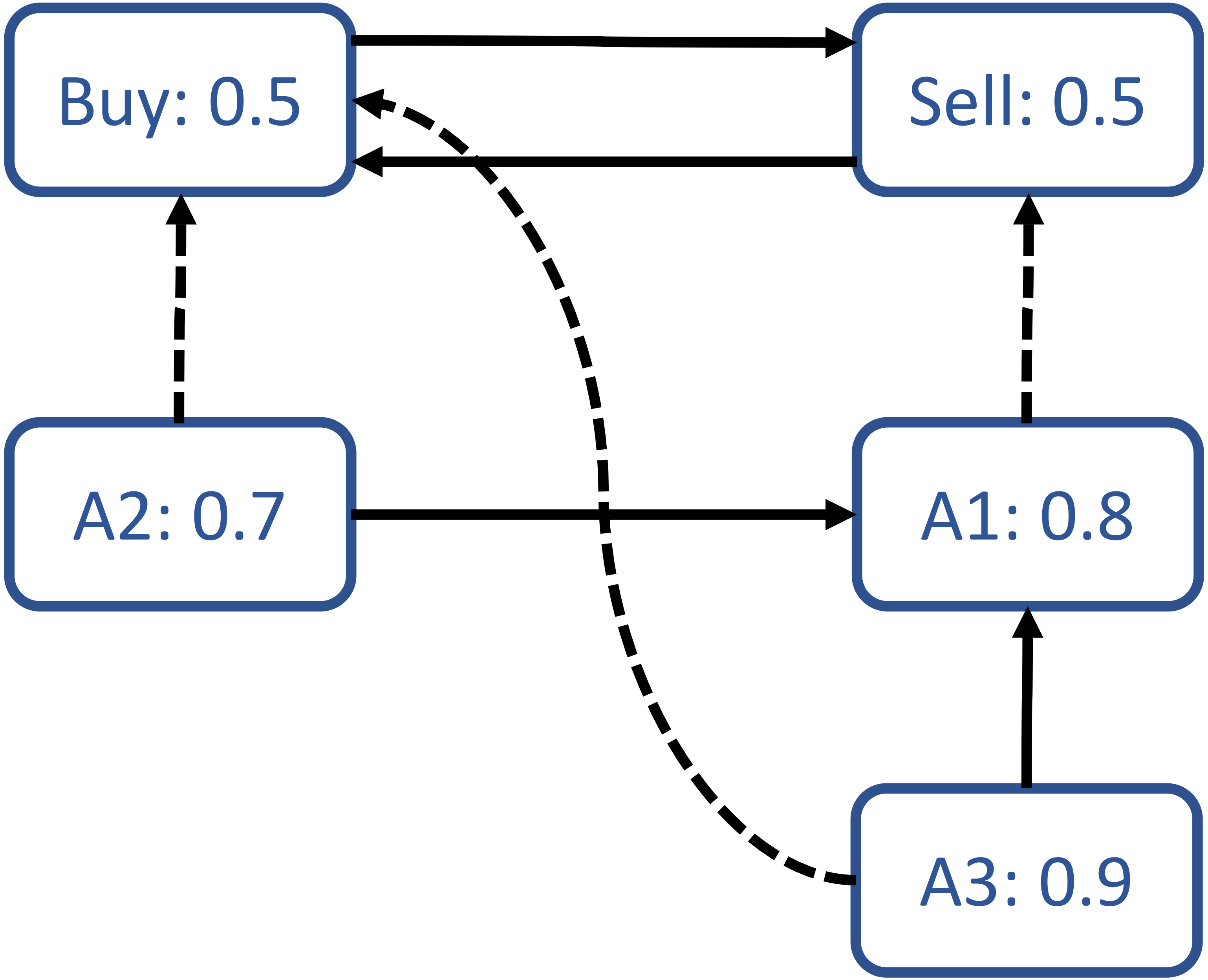
Buy: 0.5
Sell: 0.5
A1: 0.8


Buy: 0.5
Sell: 0.5
A1: 0.8
The new phone is innovative and will increase profits considerably.



Buy: 0.5
Sell: 0.5
A2: 0.7
A1: 0.8

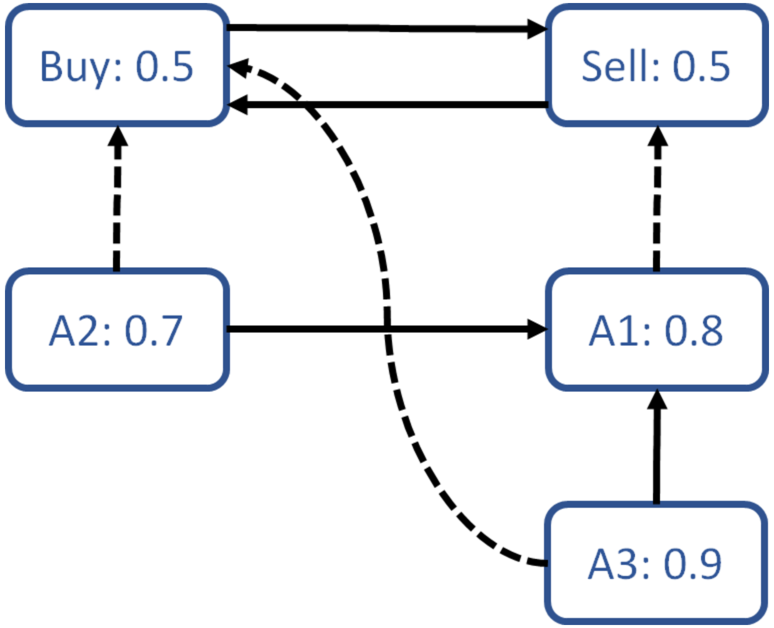

Buy: 0.5
Sell: 0.5
A2: 0.7
A1: 0.8
Investment in R&D is far beyond competitors' investment.
Company is likely to become market leader.



Buy: 0.5
Sell: 0.5
A2: 0.7
A1: 0.8
A3: 0.9

Weighted Bipolar Argumentation Graph (BAG)

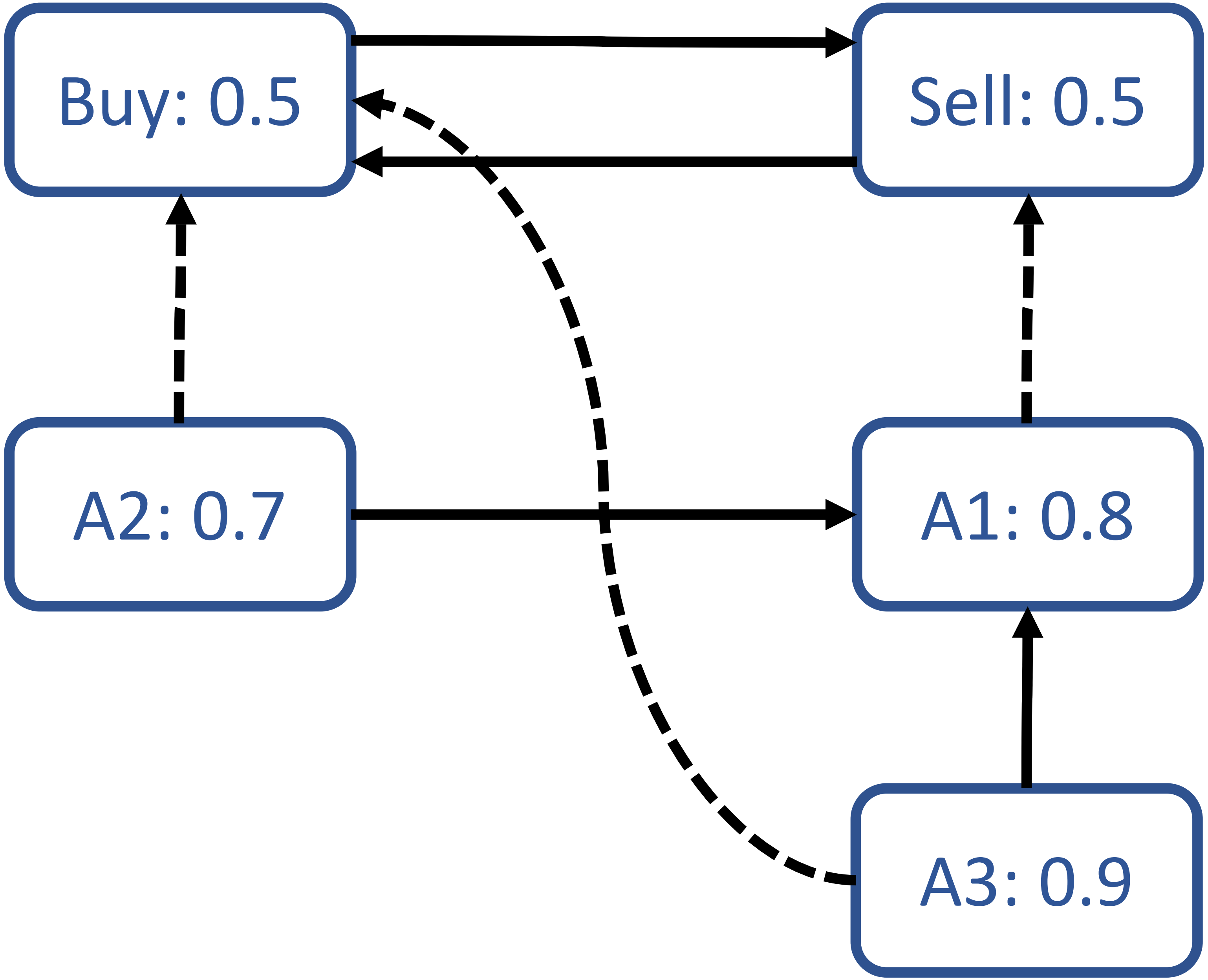
- Set of arguments
- Initial weights
- Attack and support relation



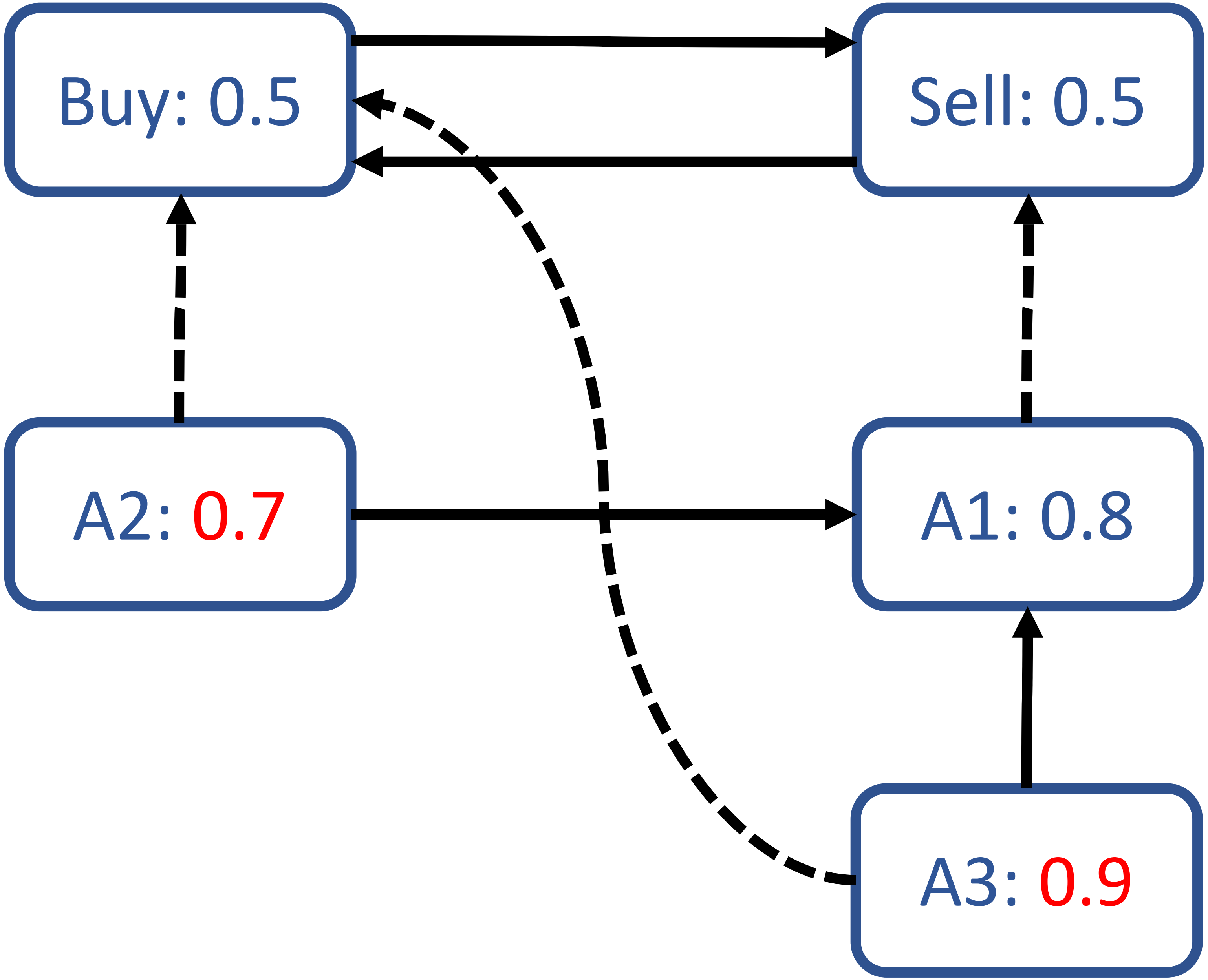
Semantics: define final strength of arguments based on

- Initial weights and
- Strength of parents

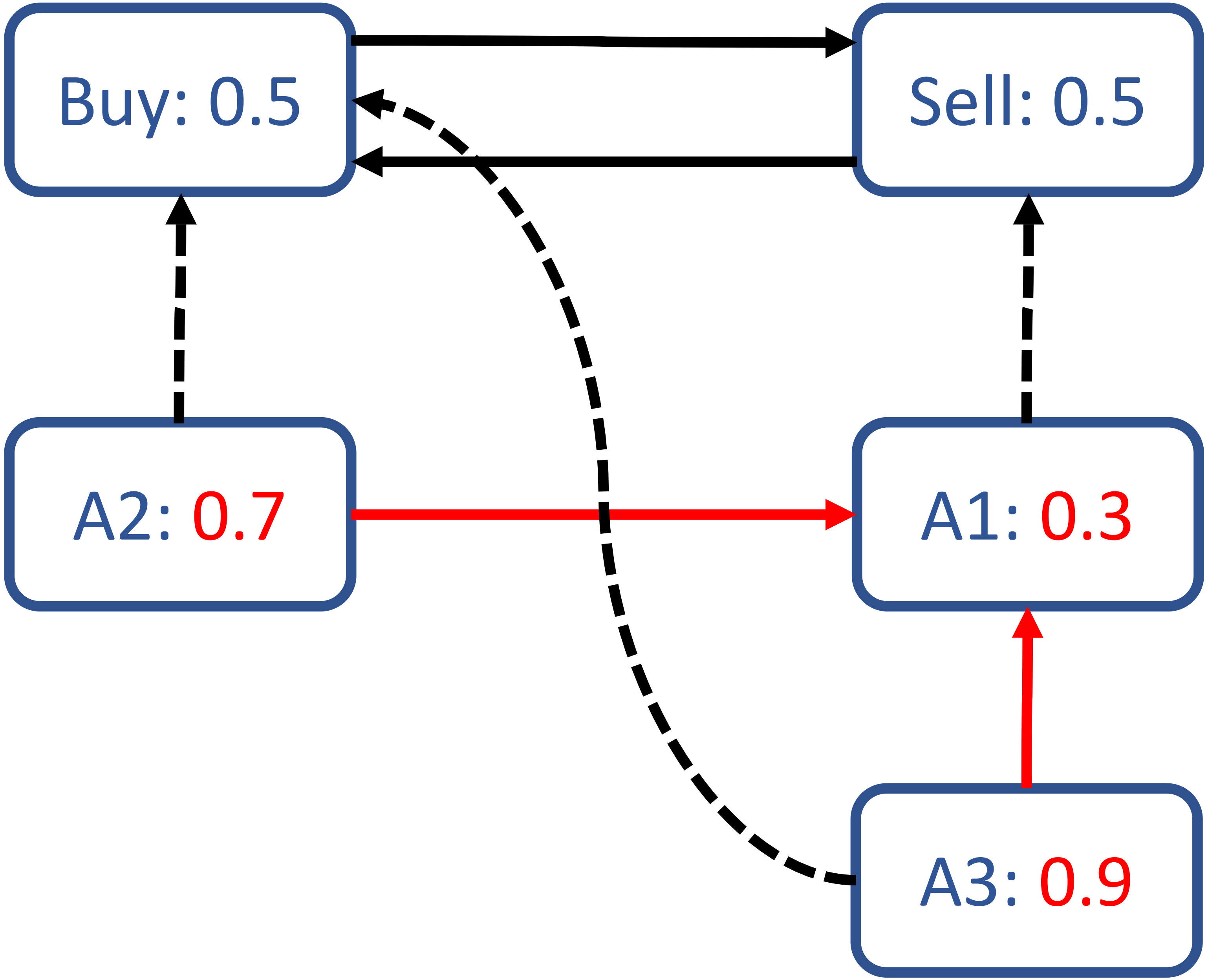
s(i) = f(w(i), Parents(i))



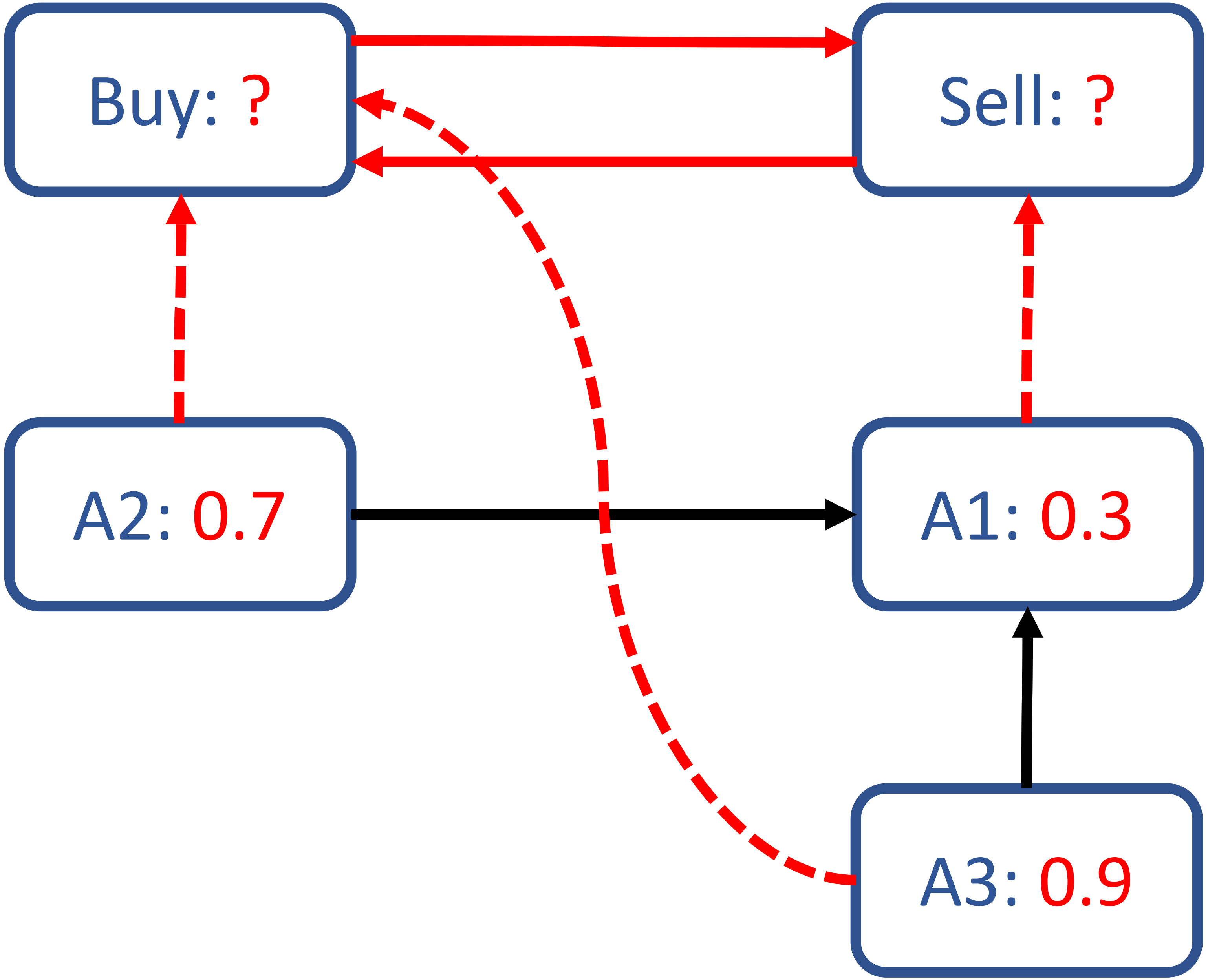
Buy: 0.5
Sell: 0.5
A2: 0.7
A1: 0.8
A3: 0.9



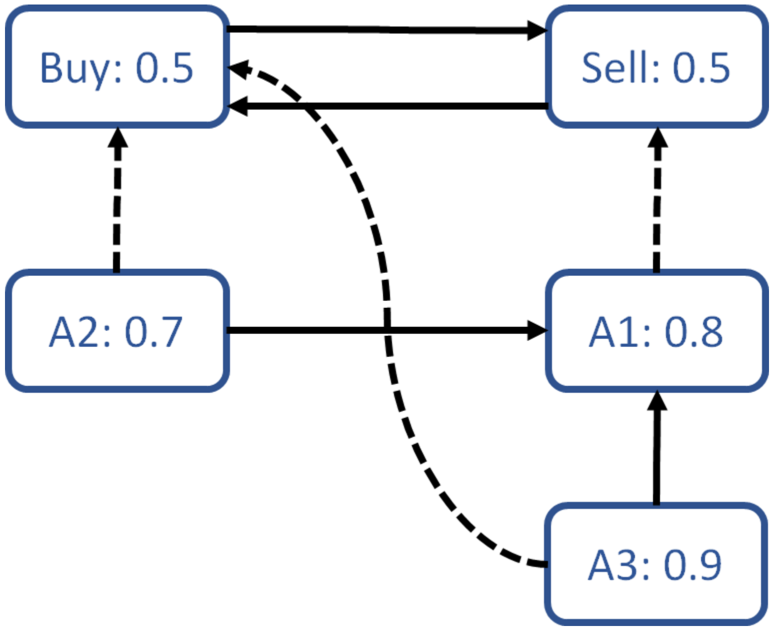
Buy: 0.5
Sell: 0.5
A2: 0.7
A1: 0.8
A3: 0.9



Buy: 0.5
Sell: 0.5
A2: 0.7
A1: 0.3
A3: 0.9


Buy: ?
Sell: ?
A2: 0.7
A1: 0.3
A3: 0.9

Computing Strength Values in Acyclic BAGs

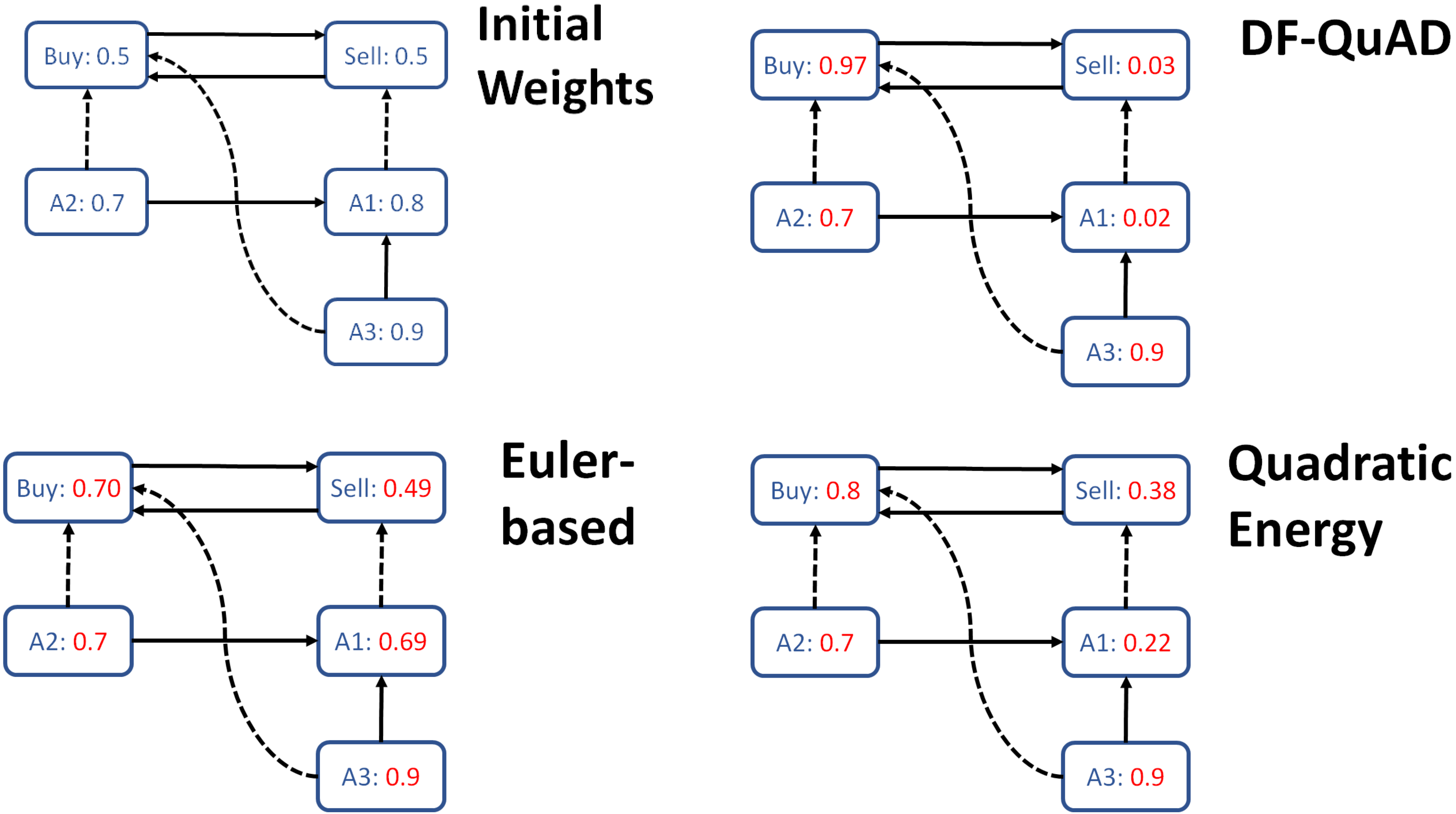


- Compute topological ordering
- Evaluate arguments in order

s(i) = f(w(i), Parents(i))

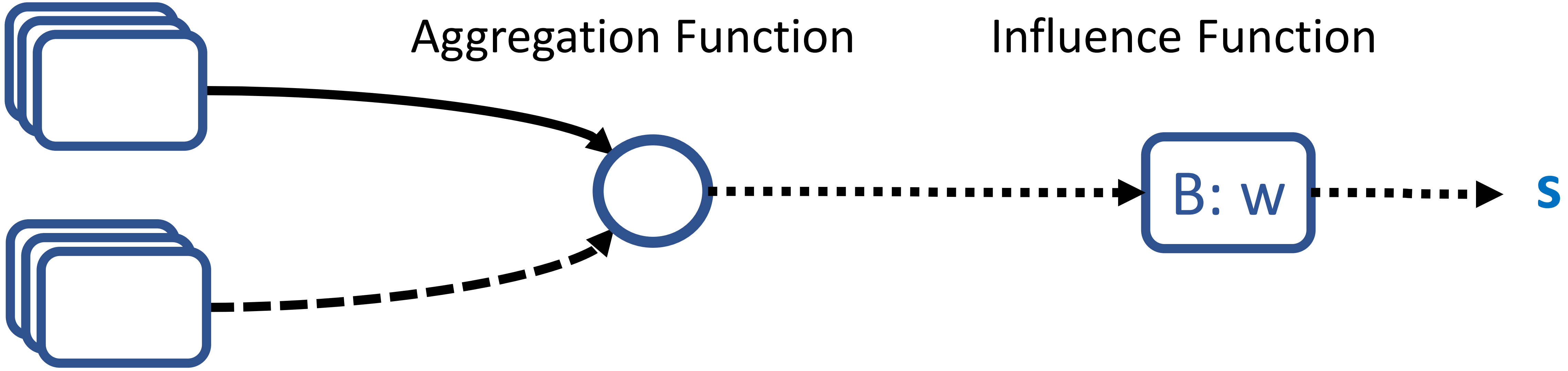
Computing Strength Values in Cyclic BAGs

- Set initial strength values to initial weights
- Update by applying update formula to all arguments simultaneously
- Repeat until process converges



Initial Weights
Buy: 0.5
Sell: 0.5
A2: 0.7
A1: 0.8
A3: 0.9
DF-QuAD
Buy: 0.97
Sell: 0.03
A2: 0.7
A1: 0.02
A3: 0.9
Euler-based
Buy: 0.70
Sell: 0.49
A2: 0.7
A1: 0.69
A3: 0.9
Quadratic Energy
Buy: 0.8
Sell: 0.38
A2: 0.7
A1: 0.22
A3: 0.9

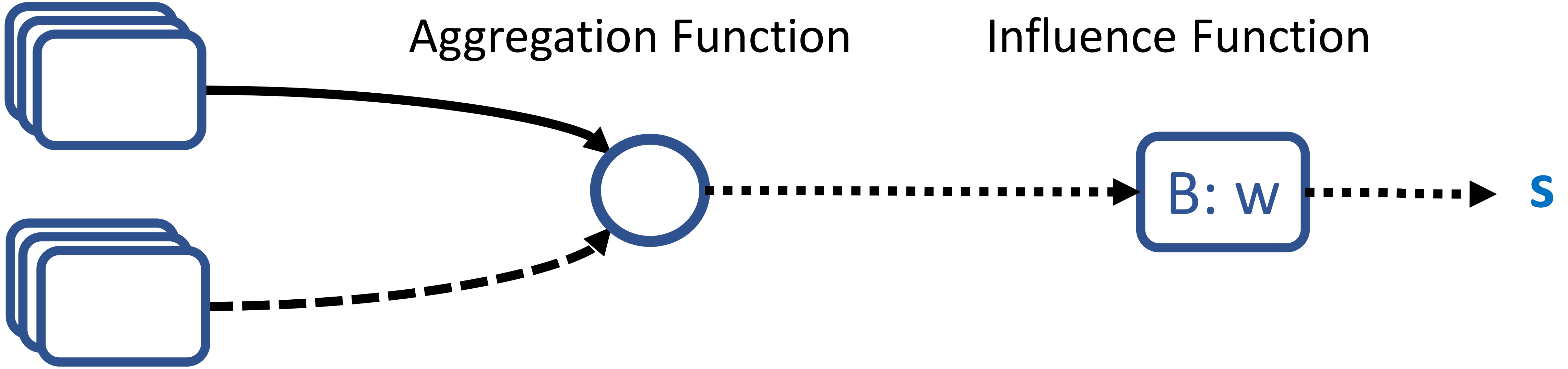
Modular Semantics *(Mossakowski, Neuhaus 2018)*



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

Mossakowski, T., & Neuhaus, F.. Modular semantics and characteristics for bipolar weighted argumentation graphs. *arXiv preprint arXiv:1807.06685*. 2018.
Amgoud, L., Cayrol, C., Lagasquie-Schiex, M. C., & Livet, P. On bipolarity in argumentation frameworks. *International Journal of Intelligent Systems*, *23*(10), 1062-1093. 2008.
Leite, J., & Martins, J. Social abstract argumentation. In Twenty-Second International Joint Conference on Artificial Intelligence (IJCAI 2011). 2011.

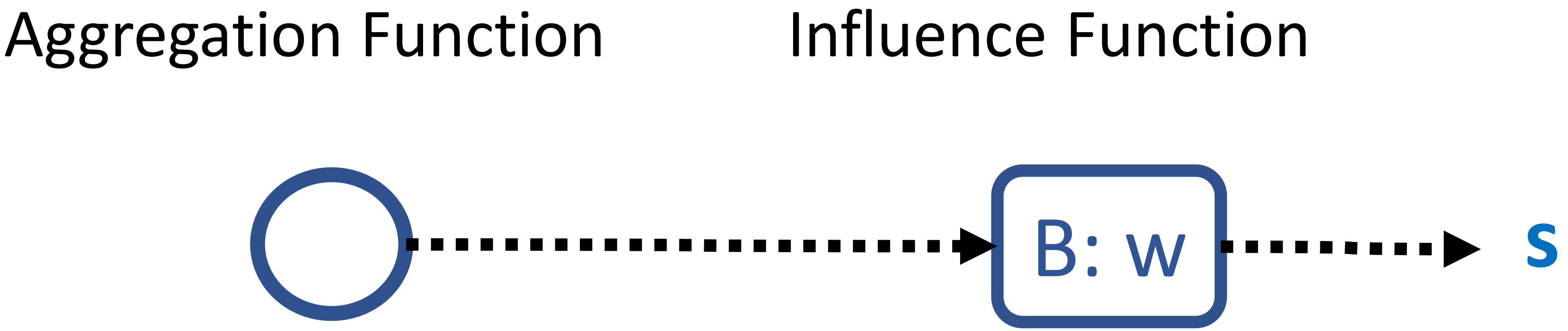
DF-QuAD



- *Aggregation:* a = $\prod_{i \in Att(B)}(1 - s_i) - \prod_{i \in Sup(B)}(1 - s_i)$
- *Influence:* s = $\begin{cases} w + w \times a & if\ a < 0 \\ w + (1 - w) \times a & else \end{cases}$

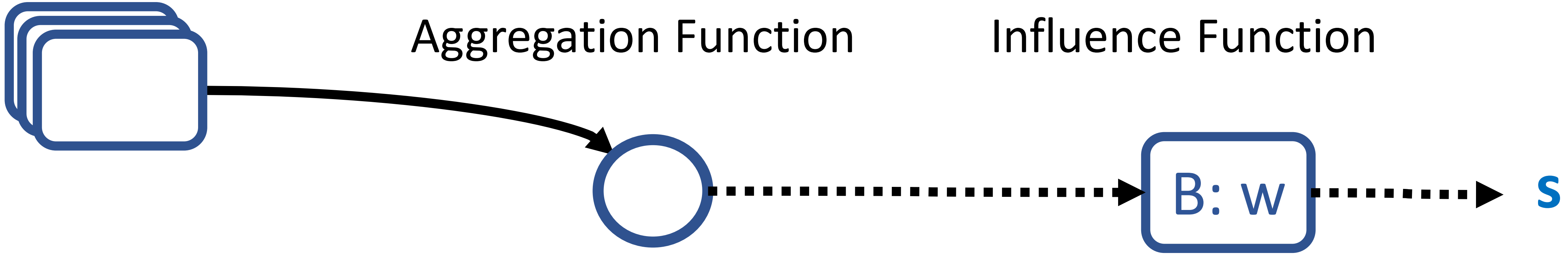
Rago, A., Toni, F., Aurisicchio, M., & Baroni, P. Discontinuity-free decision support with quantitative argumentation debates. In Fifteenth International Conference on the Principles of Knowledge Representation and Reasoning (KR 2016). 2016.

Some Special Cases: No Parents



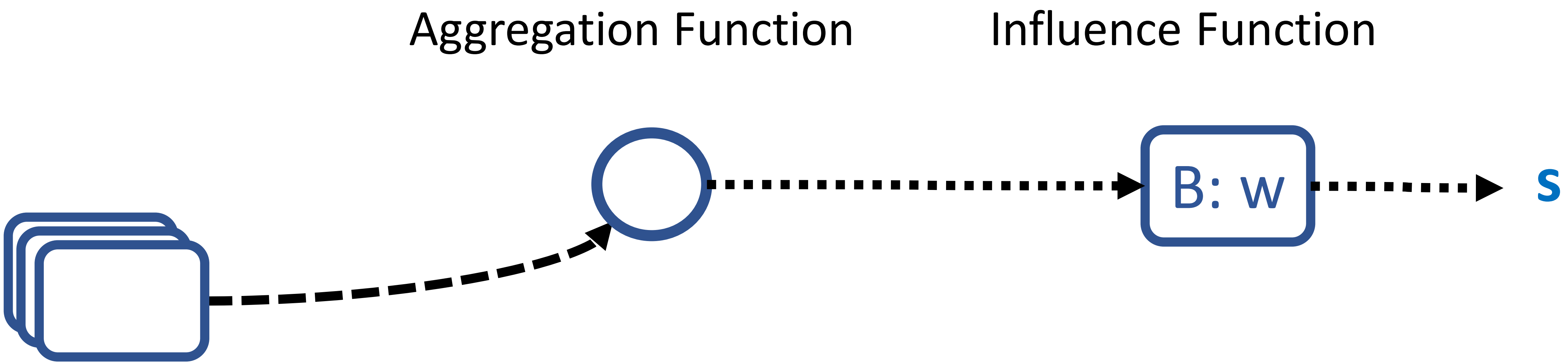
- *Aggregation:* a = 1 – 1 = 0
- *Influence:* s = w

Some Special Cases: No Supporters

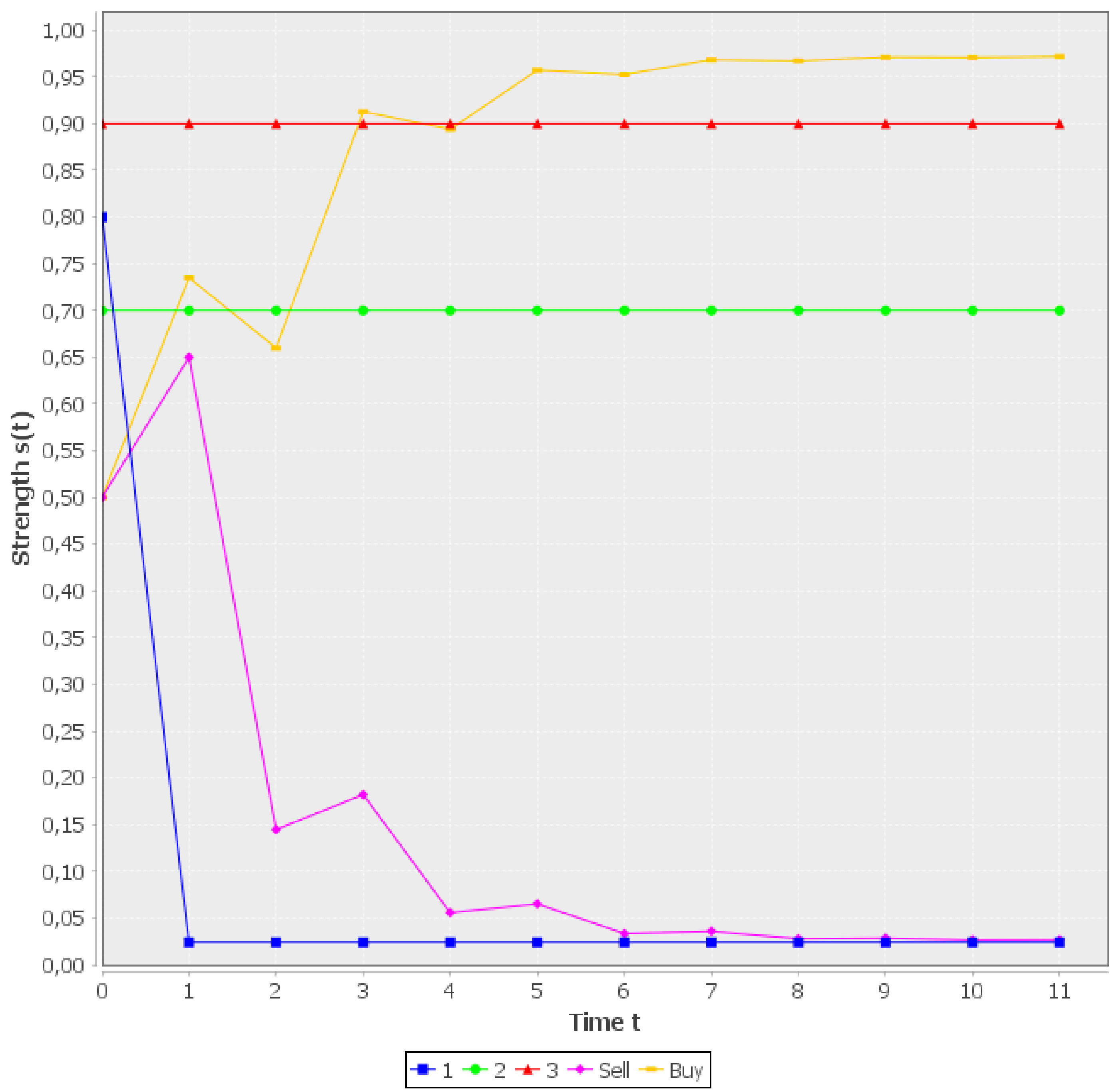


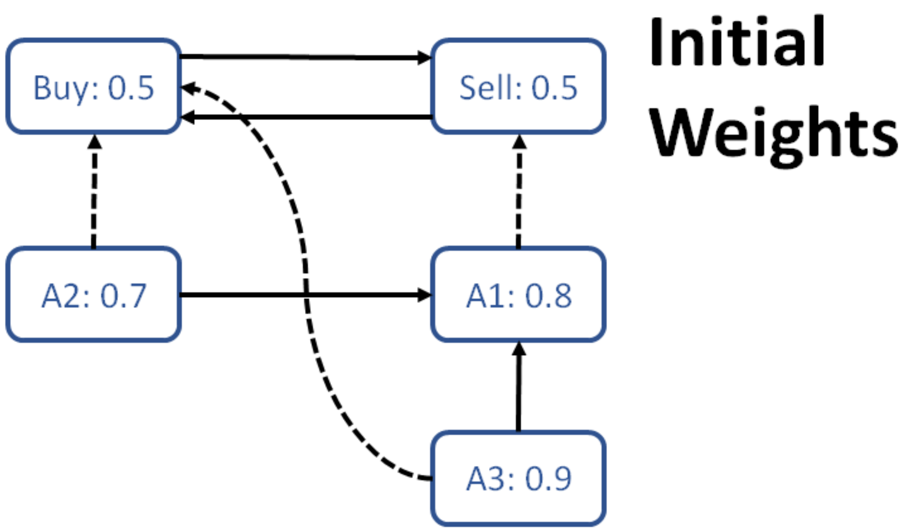
- *Aggregation:* a = $\prod_{i \in Att(B)}(1 - s_i) - 1 \leq 0$
- *Influence:* s = $w + w \times a \leq w$

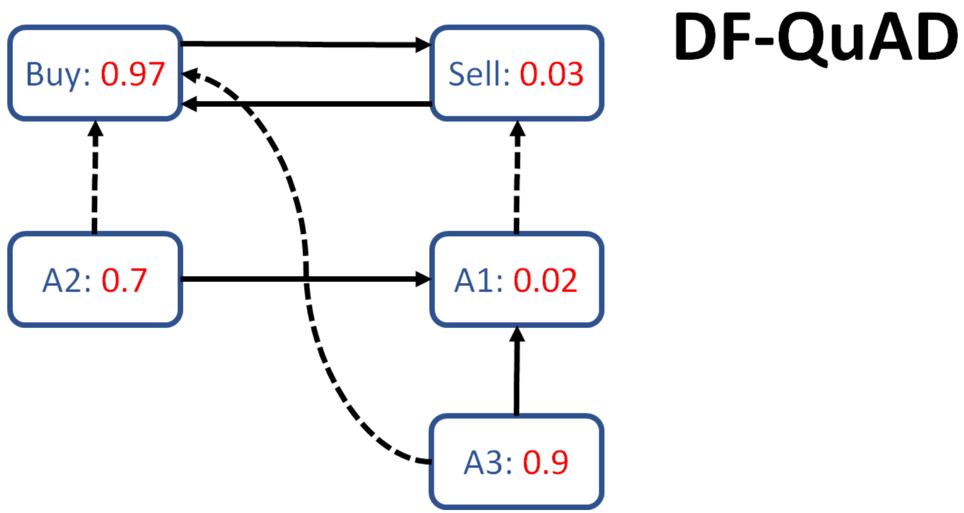
Some Special Cases: No Attackers



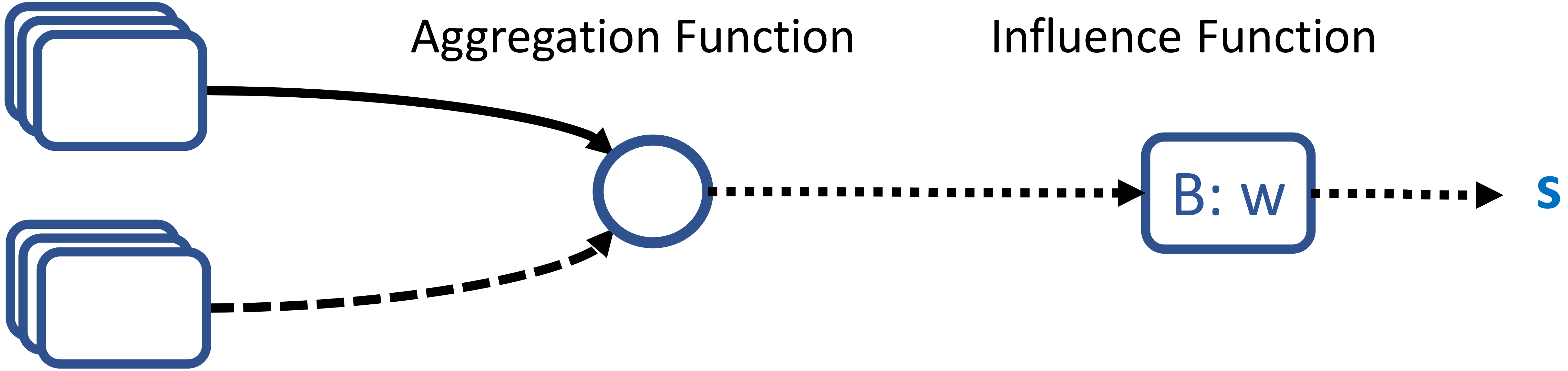
- *Aggregation:* a = $1 - \prod_{i \in \text{sup}(B)} (1 - s_i) \geq 0$
- *Influence:* s = $w + (1 - w) \times a \geq w$


1,00
0,95
0,90
0,85
0,80
0,75
0,70
0,65
0,60
0,55
0,50
0,45
0,40
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
Strength s(t)
0
1
2
3
4
5
6
7
8
9
10
11
Time t
1
2
3
Sell
Buy


Buy: 0.5
Sell: 0.5
A2: 0.7
A1: 0.8
A3: 0.9
Initial Weights


Buy: 0.97
Sell: 0.03
A2: 0.7
A1: 0.02
A3: 0.9
DF-QuAD

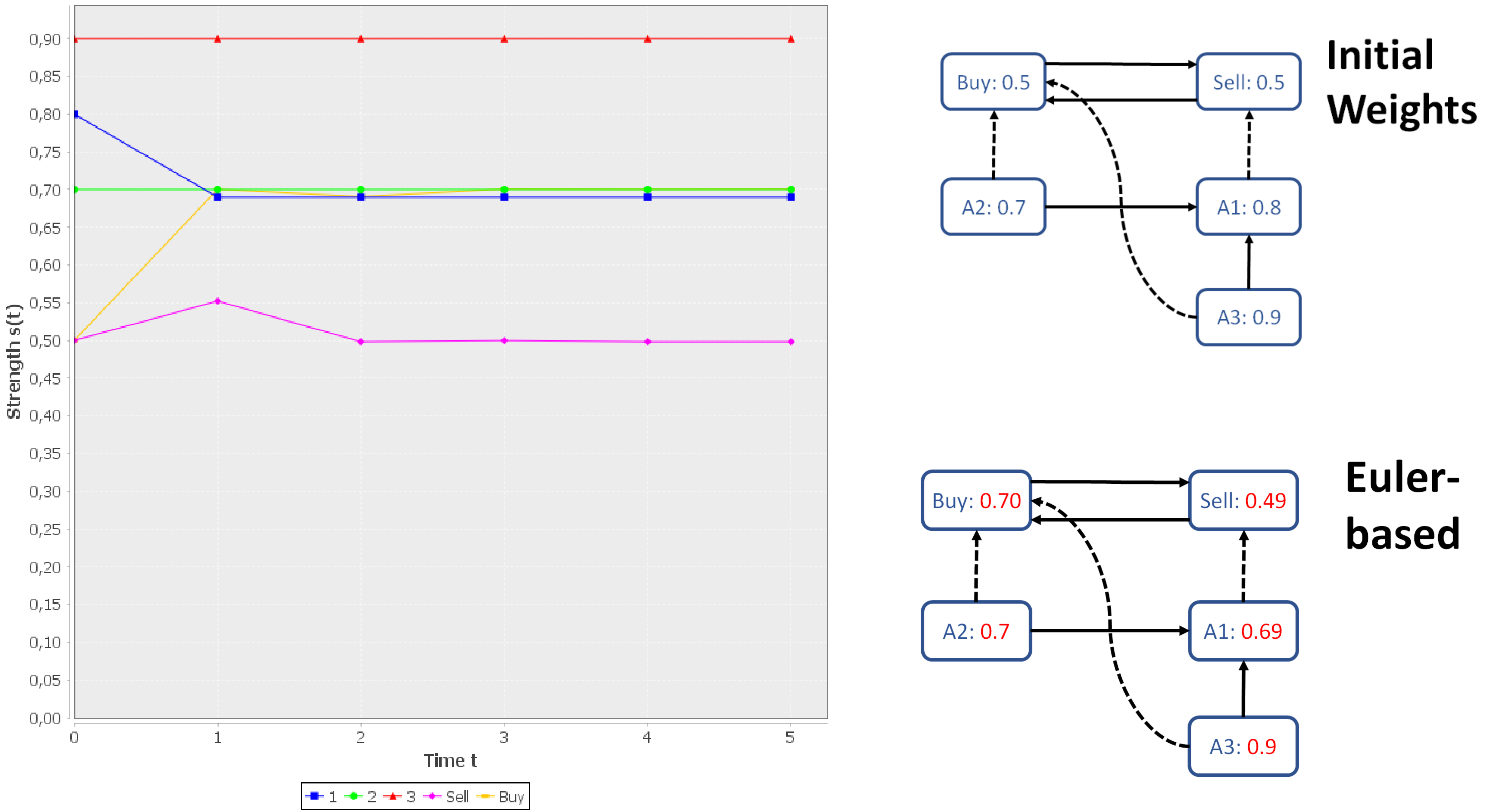
Euler-based Semantics



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

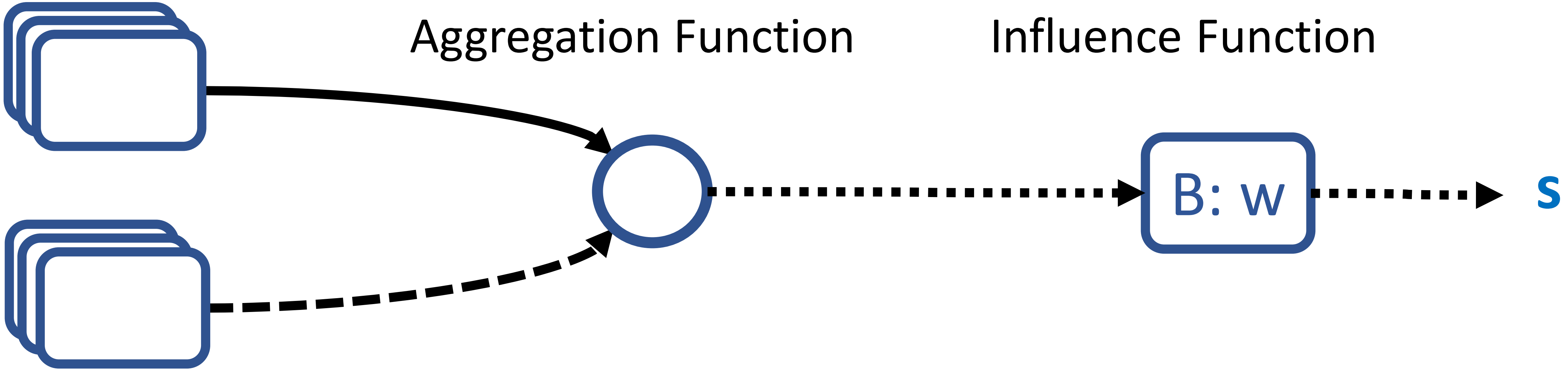
- *Influence:* s = $1 - \frac{1 - w^2}{1 + w \times e^a}$

Amgoud, L., Ben-Naim, J. Evaluation of arguments in weighted bipolar graphs. In Fourtheenth European Conference on Symbolic and Quantitative Approaches to Reasoning with Uncertainty (ECSQARU 2017). 2017.



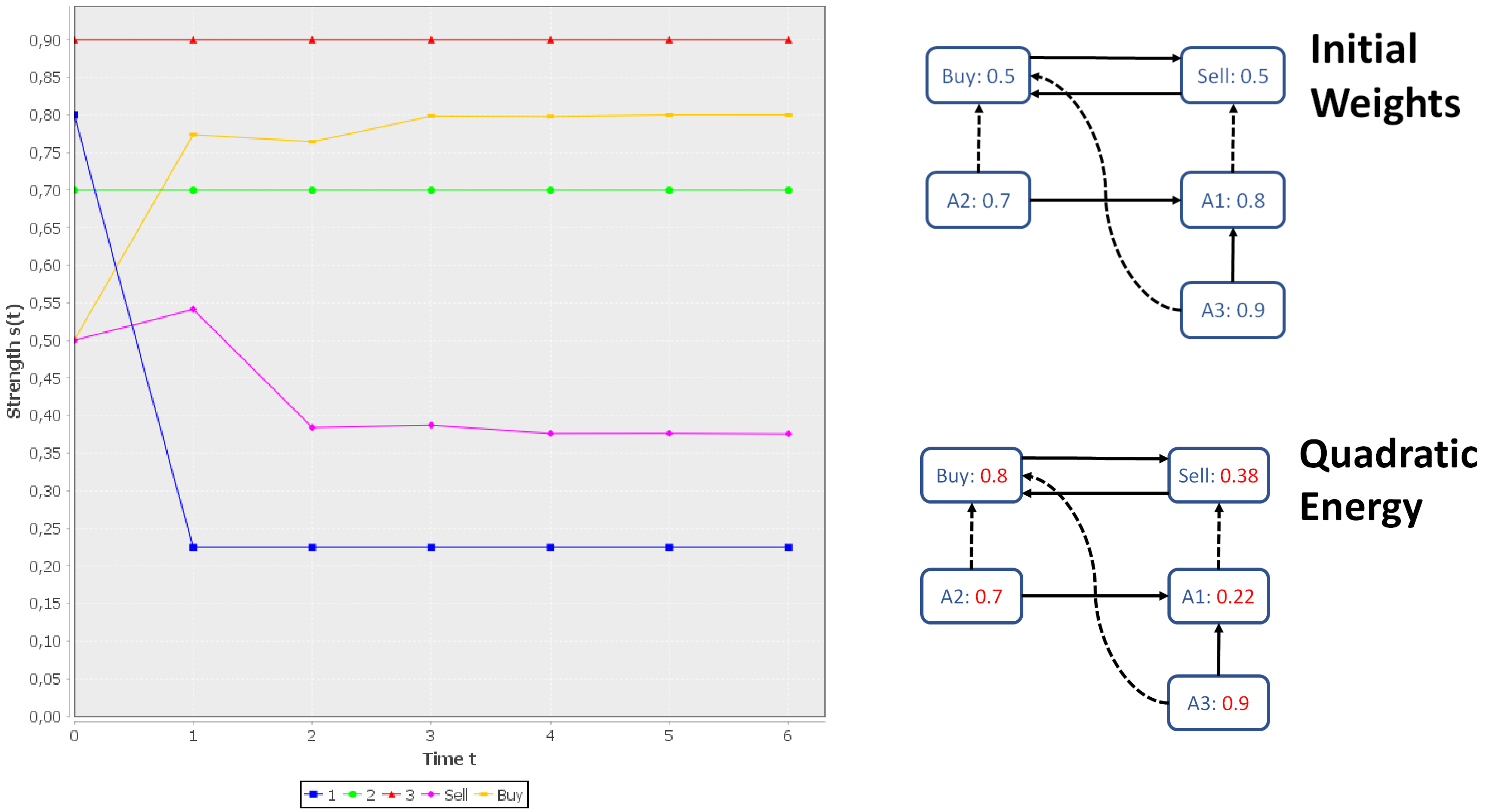
Strength s(t)
0,00
0,05
0,10
0,15
0,20
0,25
0,30
0,35
0,40
0,45
0,50
0,55
0,60
0,65
0,70
0,75
0,80
0,85
0,90
0
1
2
3
4
5
Time t
1
2
3
Sell
Buy
Initial Weights
Buy: 0.5
Sell: 0.5
A2: 0.7
A1: 0.8
A3: 0.9
Euler-based
Buy: 0.70
Sell: 0.49
A2: 0.7
A1: 0.69
A3: 0.9

Quadratic-energy Model



- *Aggregation:* a = $\sum_{i \in Sup(B)} s_i - \sum_{i \in Att(B)} s_i$
- *Influence:* s = $\begin{cases} w + (1 - w) \times \dfrac{a^2}{1+a^2} & if\ a > 0 \\ w - w \times \dfrac{a^2}{1+a^2} & else \end{cases}$

Potyka, N. Continuous dynamical systems for weighted bipolar argumentation. In *Sixteenth International Conference on Principles of Knowledge Representation and Reasoning (KR 2018)*. 2018.



Strength s(t)
Time t
0,00
0,05
0,10
0,15
0,20
0,25
0,30
0,35
0,40
0,45
0,50
0,55
0,60
0,65
0,70
0,75
0,80
0,85
0,90
0
1
2
3
4
5
6
1
2
3
Sell
Buy
Initial Weights
Buy: 0.5
Sell: 0.5
A2: 0.7
A1: 0.8
A3: 0.9
Quadratic Energy
Buy: 0.8
Sell: 0.38
A2: 0.7
A1: 0.22
A3: 0.9

Aggregation Functions

- *Product:* $\prod_{i \in Att(B)}(1 - s_i) - \prod_{i \in Sup(B)}(1 - s_i)$
- *Sum:* $\sum_{i \in Sup(B)} s_i - \sum_{i \in Att(B)} s_i$
- *Top:* $\max\{s_i : i \in Sup(B)\} - \max\{s_i : i \in Att(B)\}$

Influence Functions

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

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

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

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***

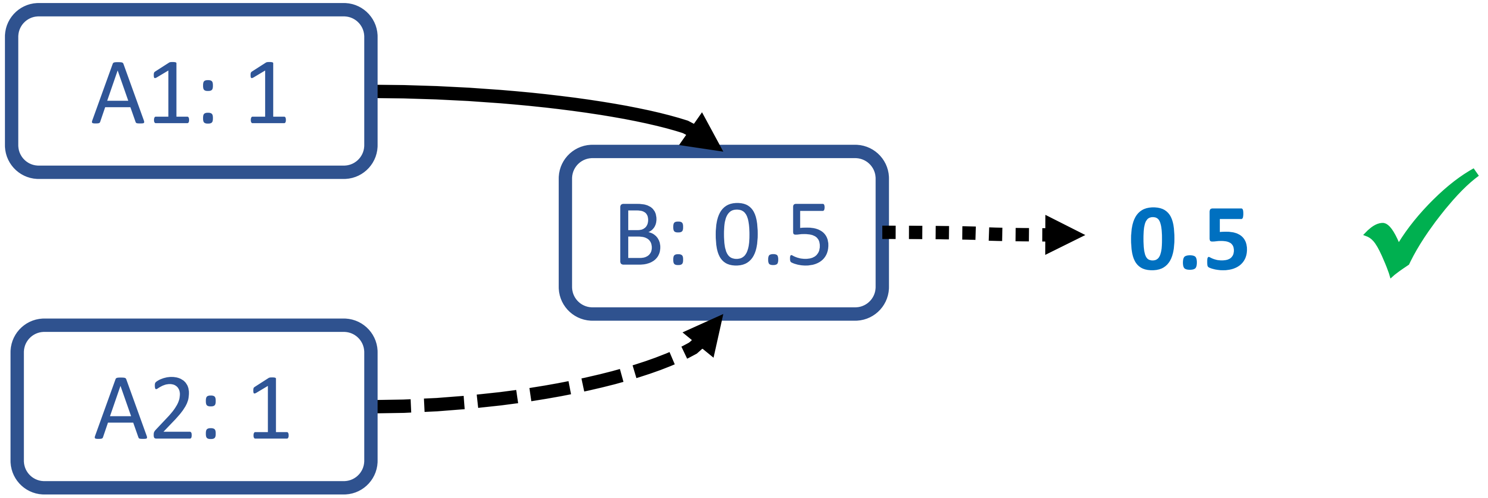
Baroni, P., Rago, A., & Toni, F. How many properties do we need for gradual argumentation? In *Thirty-Second AAAI Conference on Artificial Intelligence (AAAI 2018)*. 2018.

Balance (Intuition)

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

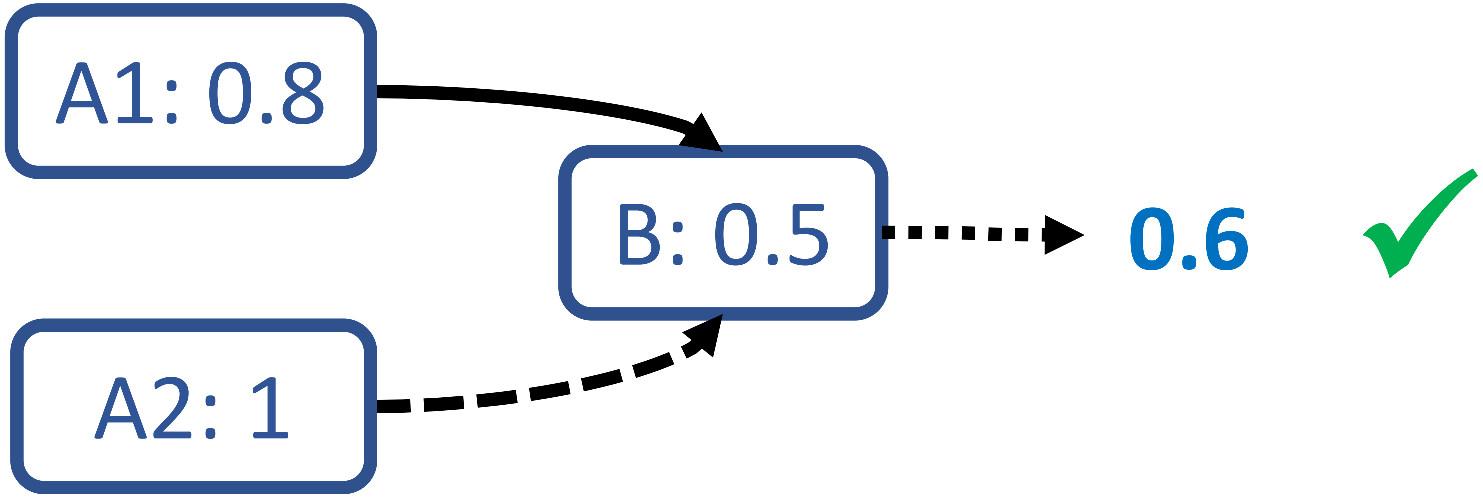
2. If attackers are „stronger (weaker) than“ supporters, strength should be smaller (larger)

Balance: DF-QuAD



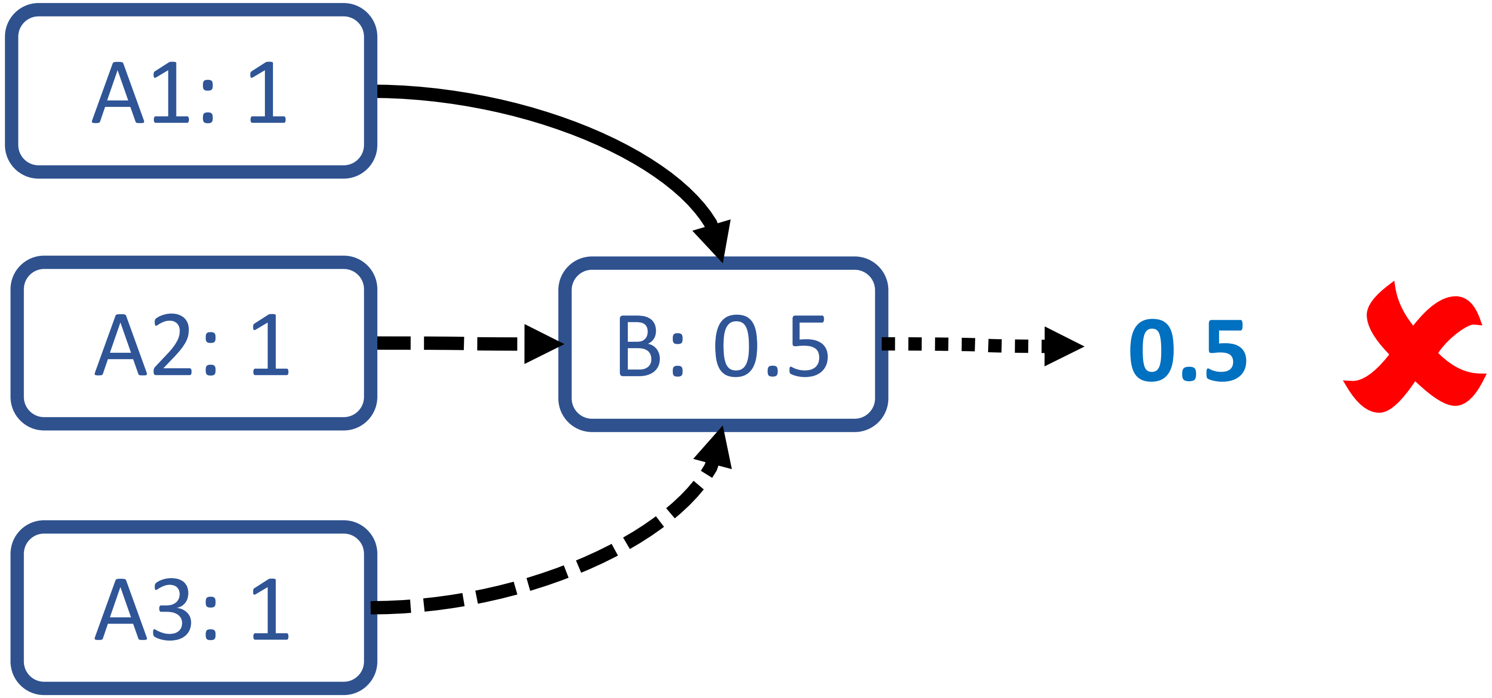
- *Aggregation:* a = (1 – 1) – (1 - 1) = 0
- *Influence:* s = 0.5 + (1 – 0.5) × 0 = 0.5

Balance: DF-QuAD



- *Aggregation:* a = (1 – 0.8) – (1 - 1) = 0.2
- *Influence:* s = 0.5 + (1 – 0.5) × 0.2 = 0.6

Balance: DF-QuAD



Product Aggregation and *Top Aggregation* can violate balance

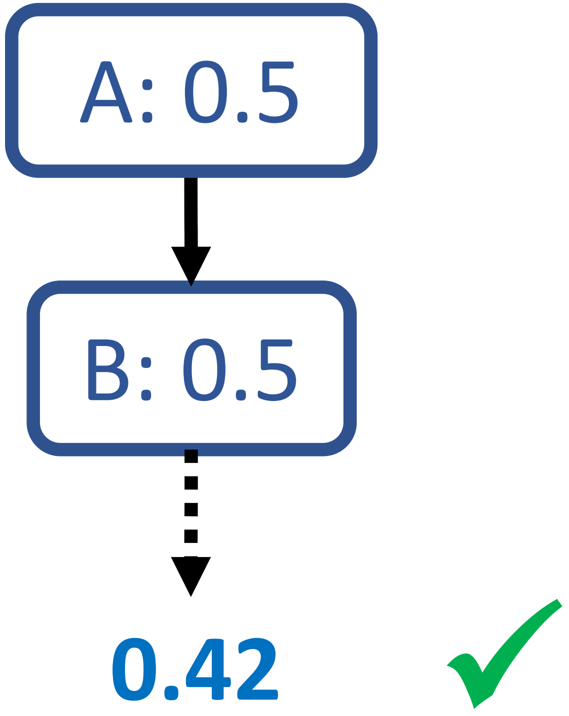
- *Aggregation:* a = (1 – 1) – (1 - 1) × (1 - 1) = 0
- *Influence:* s = 0.5 + (1 – 0.5) × 0 = 0.5

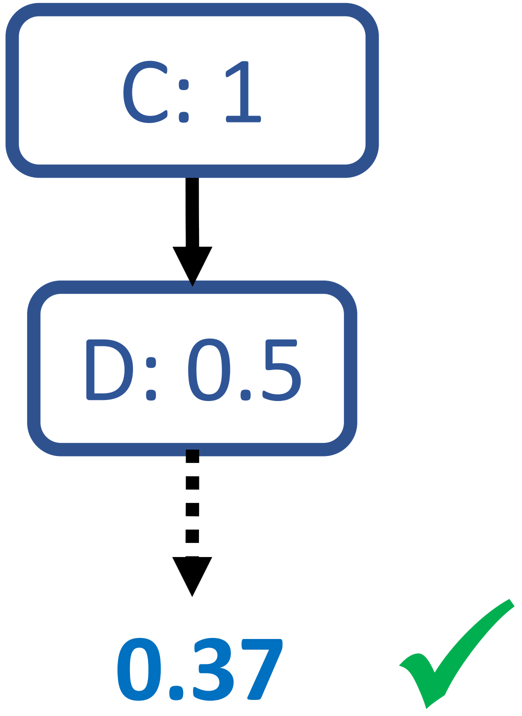
Monotonicity (Intuition)

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

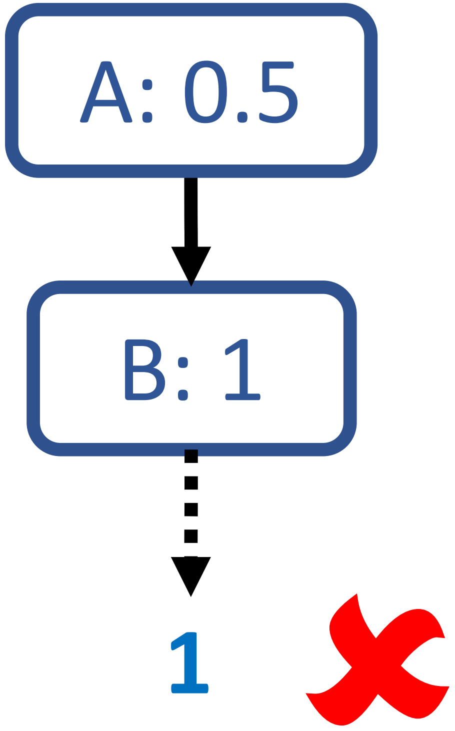


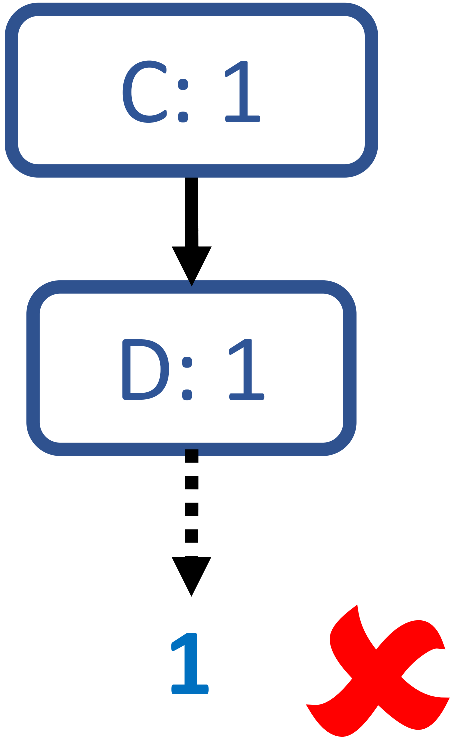


- a = -0.5
- s = $1 - \frac{1 - 0.5^2}{1 + 0.5 \times \exp(-0.5)} \approx 0.42$

- a = -1
- s = $1 - \frac{1 - 0.5^2}{1 + 0.5 \times \exp(-1)} \approx 0.37$

Monotonicity: Euler-based Semantics





Euler-based Influence violates monotonicity in boundary cases

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

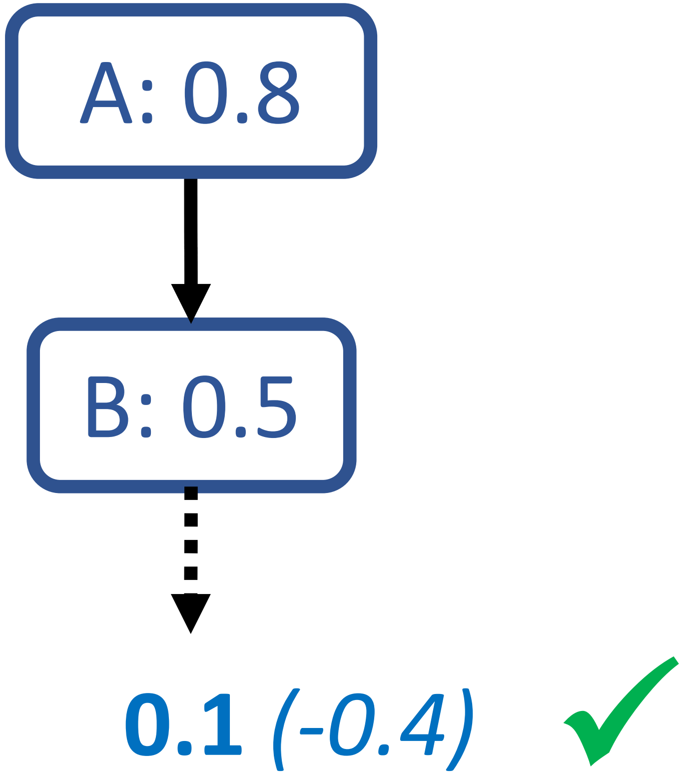
- a = -1
- s = $1 - \frac{1 - 1^2}{1 + 1 \times \exp(-1)} = 1$

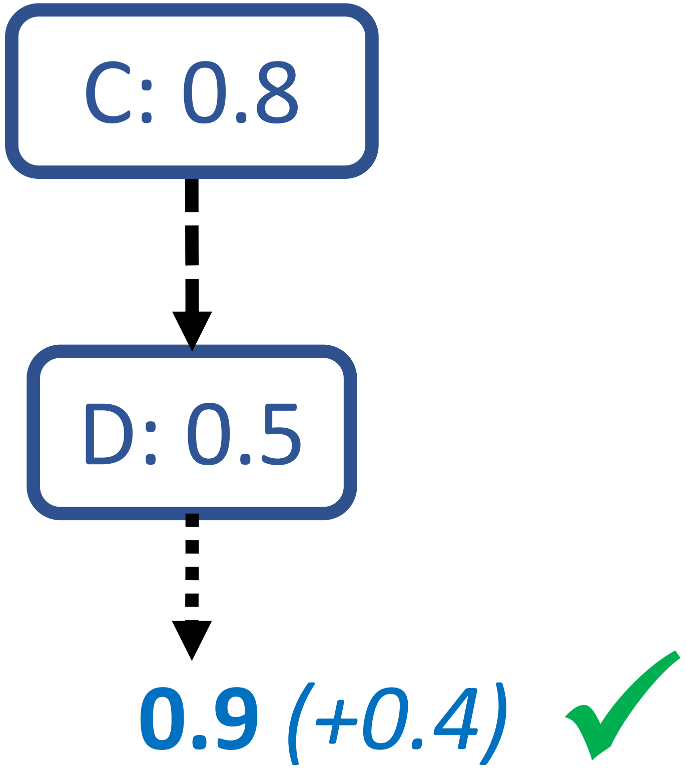
Beyond Balance and Monotonicity (AAMAS 2019)

- **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)

Potyka, N. Extending Modular Semantics for Bipolar Weighted Argumentation. In Proceedings of the 18th International Conference on Autonomous Agents and MultiAgent Systems (AAMAS 2019). 2019.

Duality: DF-QuAD

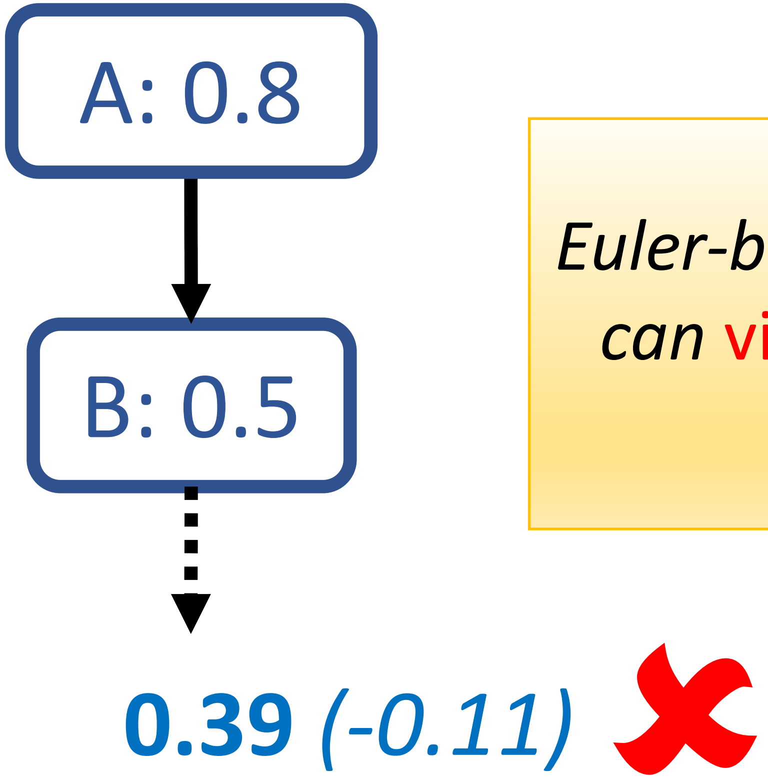




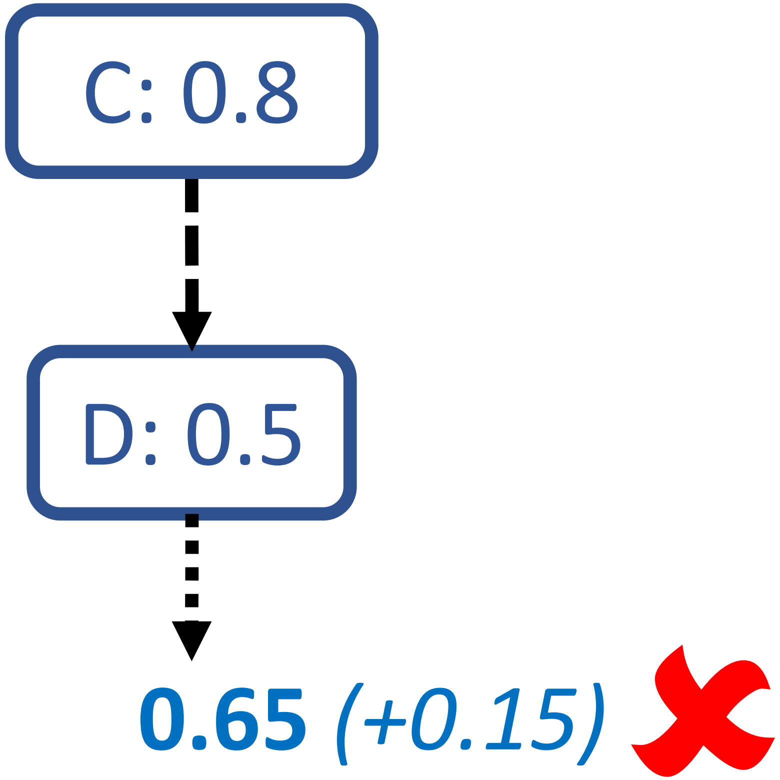
- a = $(1-0.8)-1$ = -0.8
- s = $0.5 - 0.5 \times 0.8 = 0.1$

- a = $1 - (1-0.8) = 0.8$
- s = 0.5 + (1 - 0.5) × 0.8 = 0.9

Duality: Euler-based



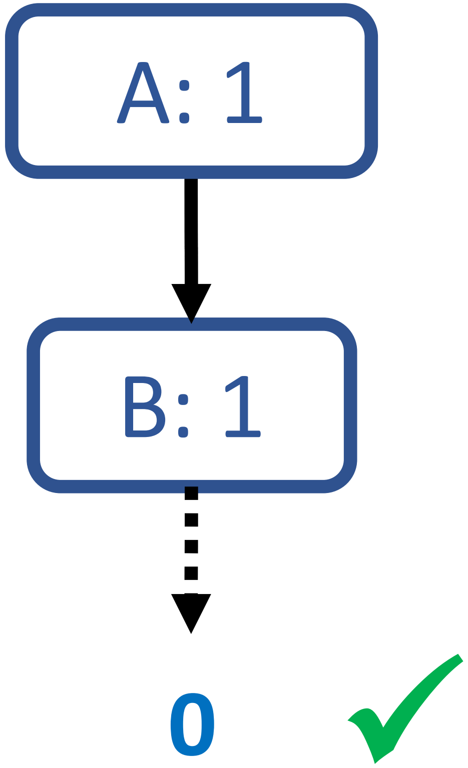
Euler-based Influence can violate Duality

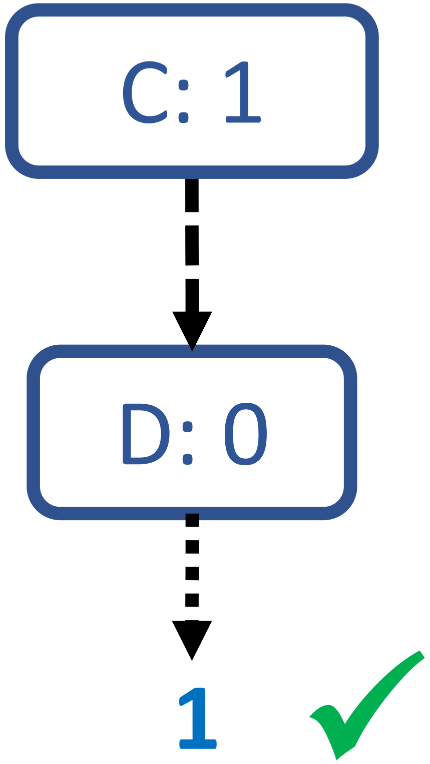


- a = -0.8
- s = $1 - \frac{1 - 0.5^2}{1 + 0.5 \times \exp(-0.8)} = 0.39$

- a = 0.8
- s = $1 - \frac{1 - 0.5^2}{1 + 0.5 \times \exp(0.8)} = 0.65$

Open-Mindedness: DF-QuAD

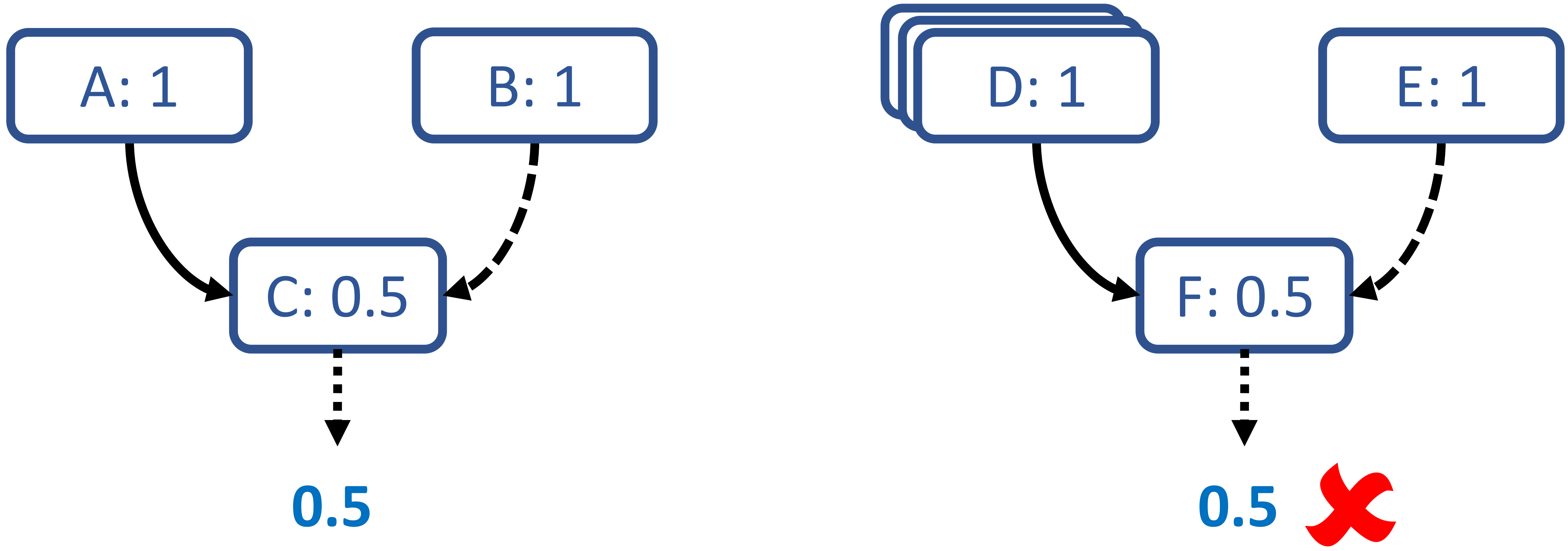




- a = (1 − 1) – 1 = -1
- s = 1 − 1 × 1 = 0

- a = 1 − (1 − 1) = 1
- s = 0 + (1 - 0) × 1 = 1

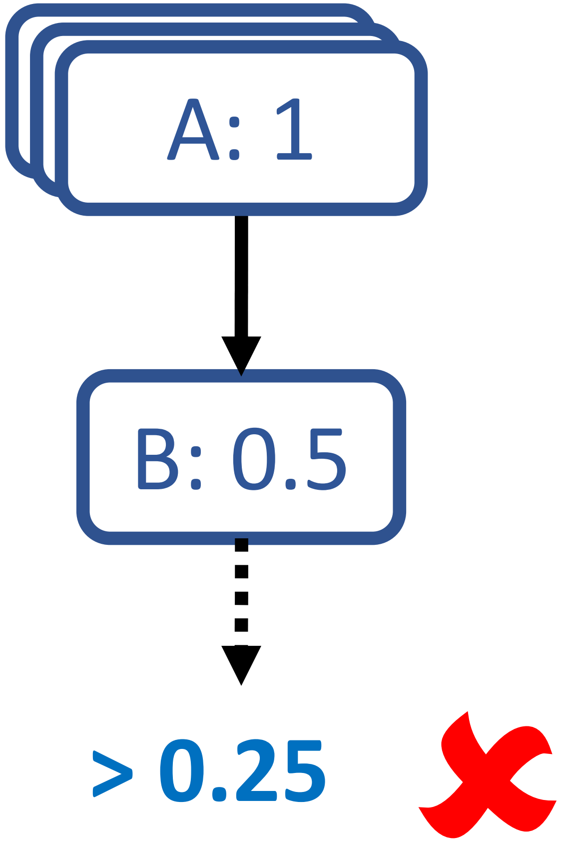
Open-Mindedness: DF-QuAD



- a = 0 – 0 = 0
- s = 0.5 − 0.5 × 0 = 0

- a = 0 − 0 = 0
- s = 0.5 + (1 – 0.5) × 0 = 0.5

Open-Mindedness: Euler-based



Euler-based Influence can violate Open-Mindedness

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

Summary: Potential Semantical Problems

Aggregation Function	Balance	Monotonicity	Duality	Open-Mindedness
Product	(✘)	(✘)		(✘)
Sum				
Top	(✘)	(✘)		(✘)

Influence Function	Balance	Monotonicity	Duality	Open-Mindedness
Linear				
Euler-based		(✘)	✘	✘
qmax				

Aggregation/ Influence Function	Balance	Monotonicity	Duality	Open-Mindedness
Sum/ qmax	✓	✓	✓	✓

Some Further Readings about Weighted Semantics

- *Attack-only Graphs*

Amgoud, L., Ben-Naim, J., Doder, D., & Vesic, S. Acceptability Semantics for Weighted Argumentation Frameworks. In Twenty-Sixth International Joint Conference on Artificial Intelligence (IJCAI 2017). 2017.

- *Support-only Graphs*

Amgoud, L., & Ben-Naim, J. Evaluation of arguments from support relations: Axioms and semantics. In Twenty-Fifth International Joint Conference on Artificial Intelligence (IJCAI 2016). 2016.

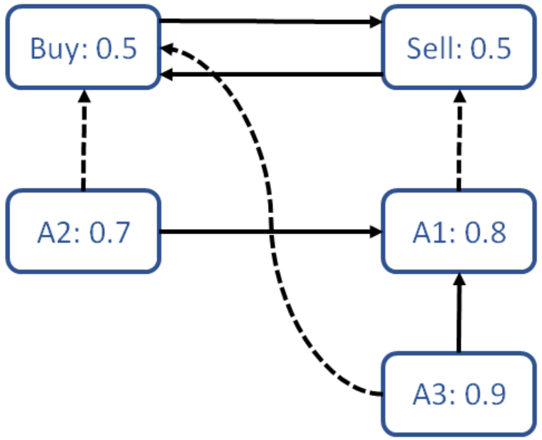
- *Bipolar Graphs*

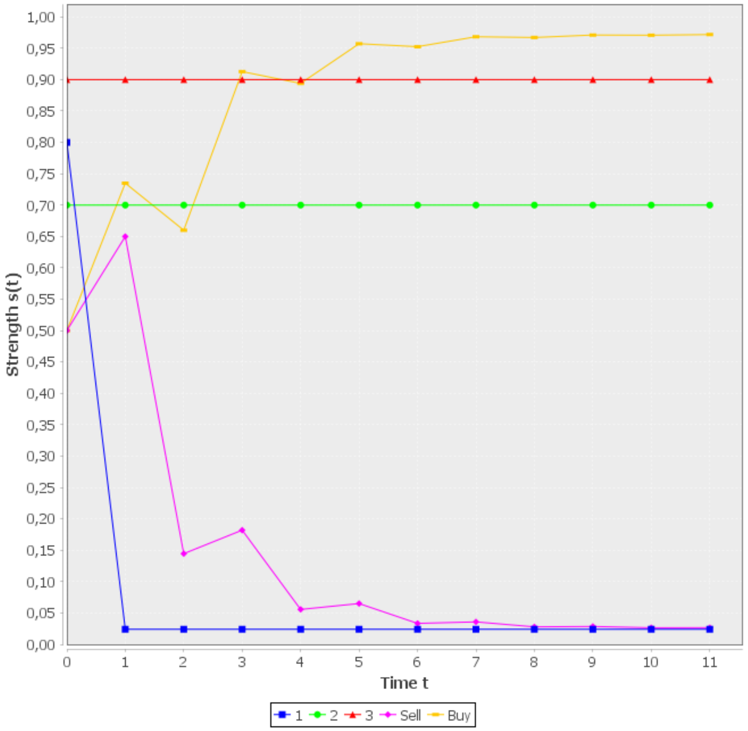
Baroni, P., Romano, M., Toni, F., Aurisicchio, M., & Bertanza, G. Automatic evaluation of design alternatives with quantitative argumentation. Argument & Computation, 6(1), 24-49. 2015.

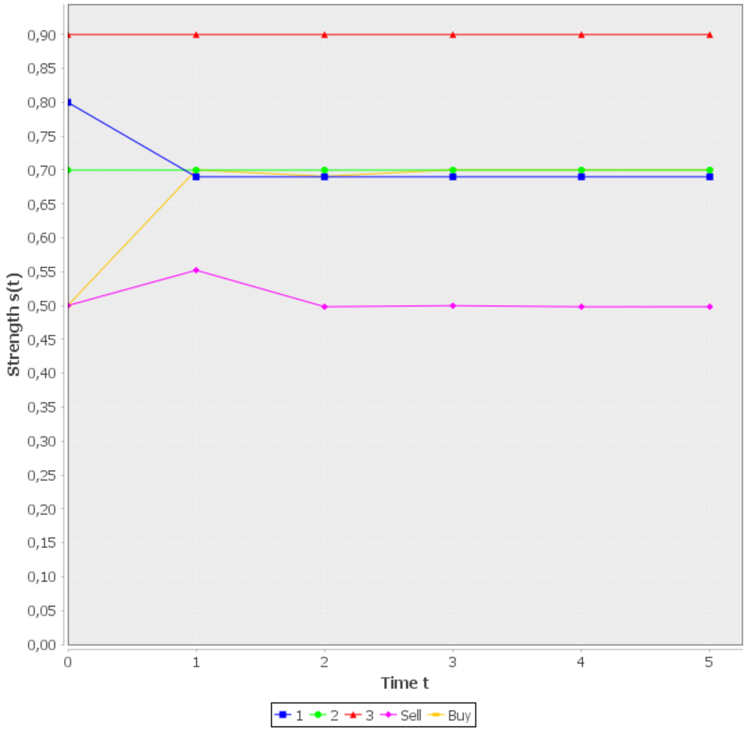
Gradual Bipolar Argumentation

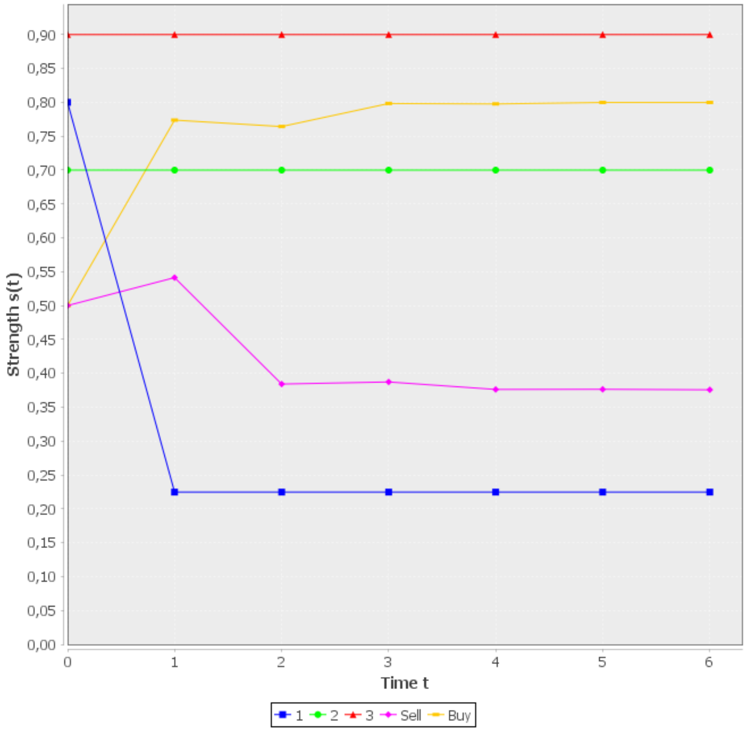
Computation

Initial Weights









Computing Strength Values

$i \leftarrow 0$

FOR $a = 1,\ldots,n$

$\quad s^{(i)}(a) = w(a)$

DO

$\quad i \leftarrow i + 1$

$\quad$**FOR** $a = 1,\ldots,n$

$\quad\quad s^{(i)}(a) = f(w(a), Parents(a), s^{(i-1)})$

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

$s \leftarrow s^{(i)}$

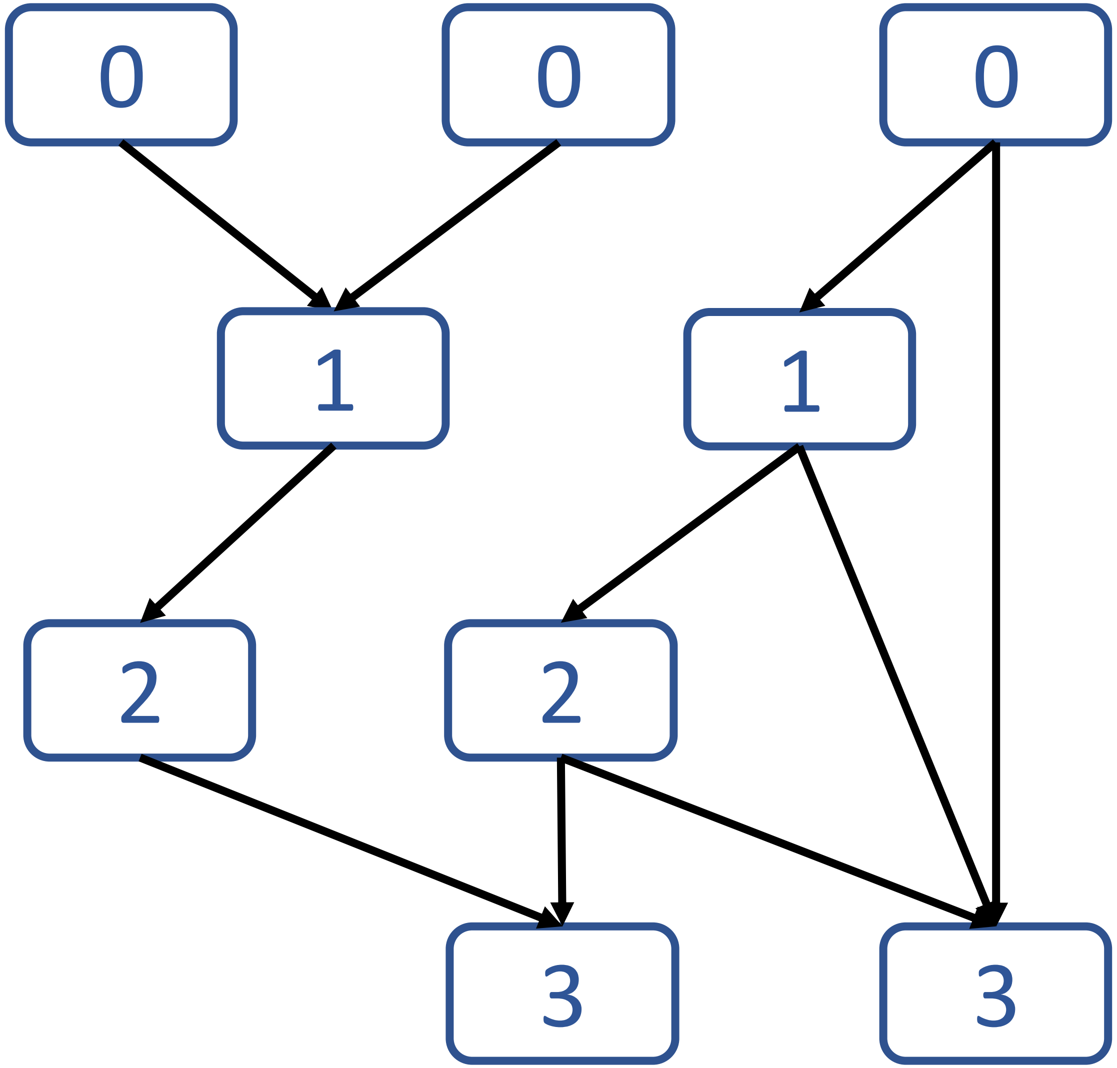
Initialization with initial weights

Update strength values simultaneously until convergence

Depth in Acyclic BAGs

Depth(i) *is defined as*

$$\begin{cases} 0 & \text{if } Parents(i) = \emptyset \\ 1 + \max \{depth(j) : j \in Parents(i)\} & \text{else} \end{cases}$$



Convergence in Acyclic BAGs

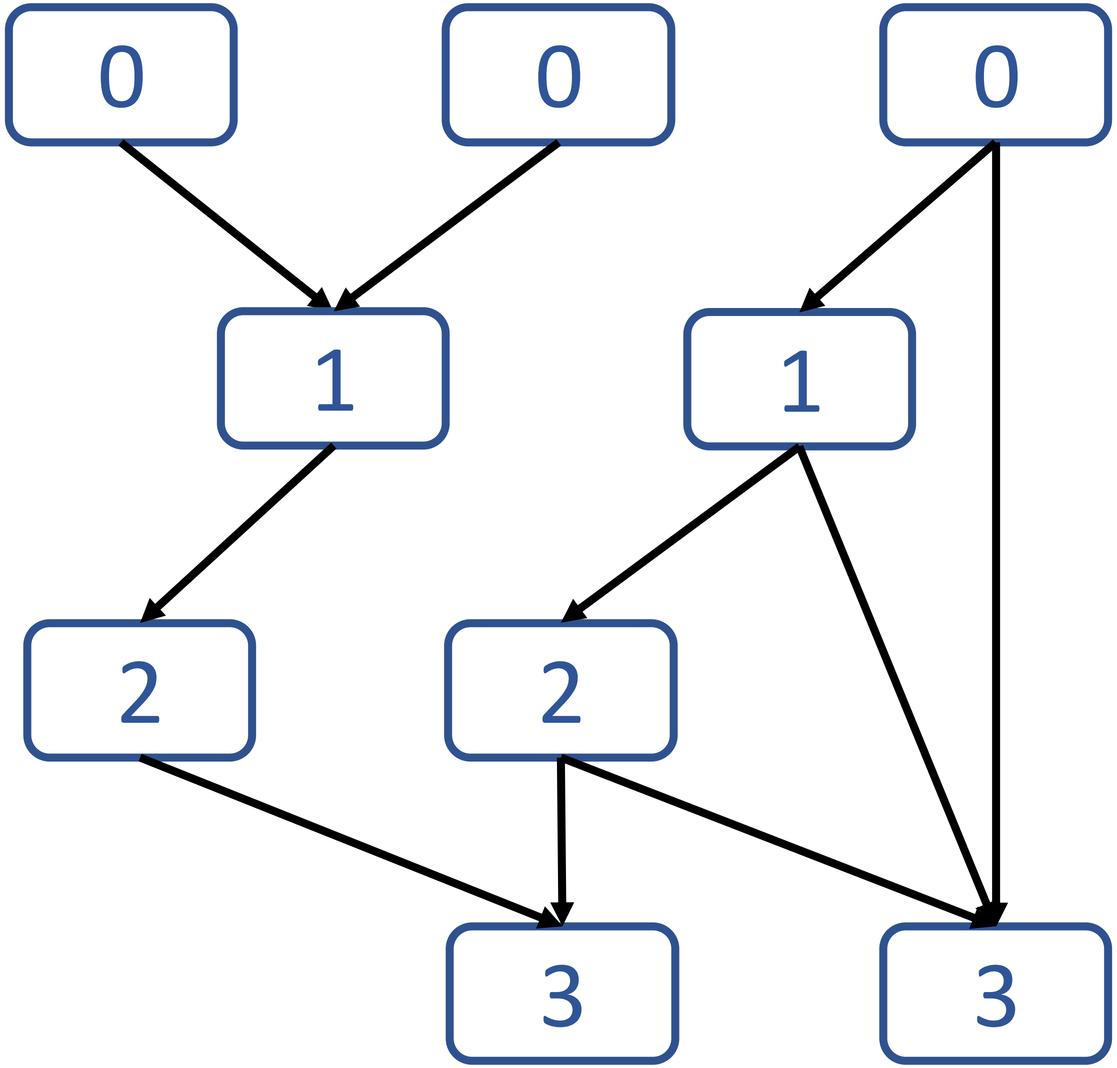
Lemma
If depth(A)=d, then strength of A remains unchanged after iteration d.

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

$O(n^2)$ updates

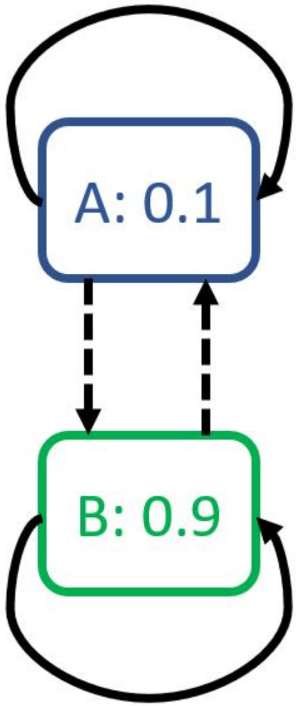
Theorem
Computing strength values once according to topological ordering yields the same result.

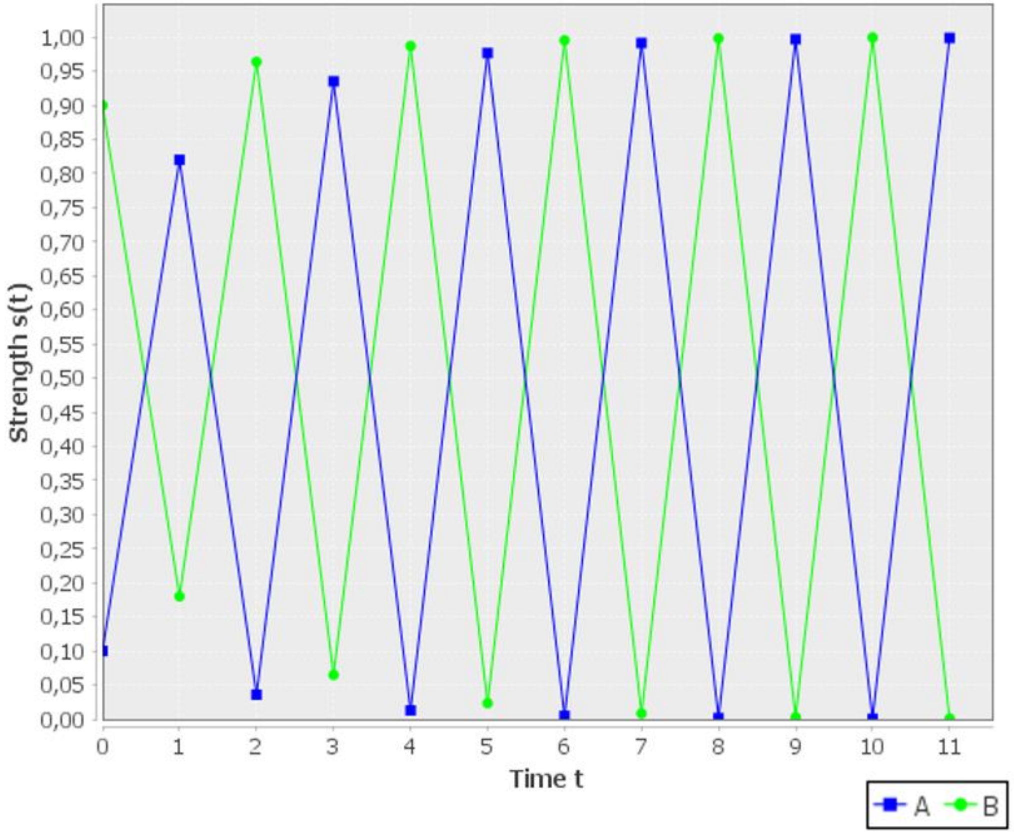
O(n+m) for ordering + O(n) updates



Convergence in Cyclic BAGs

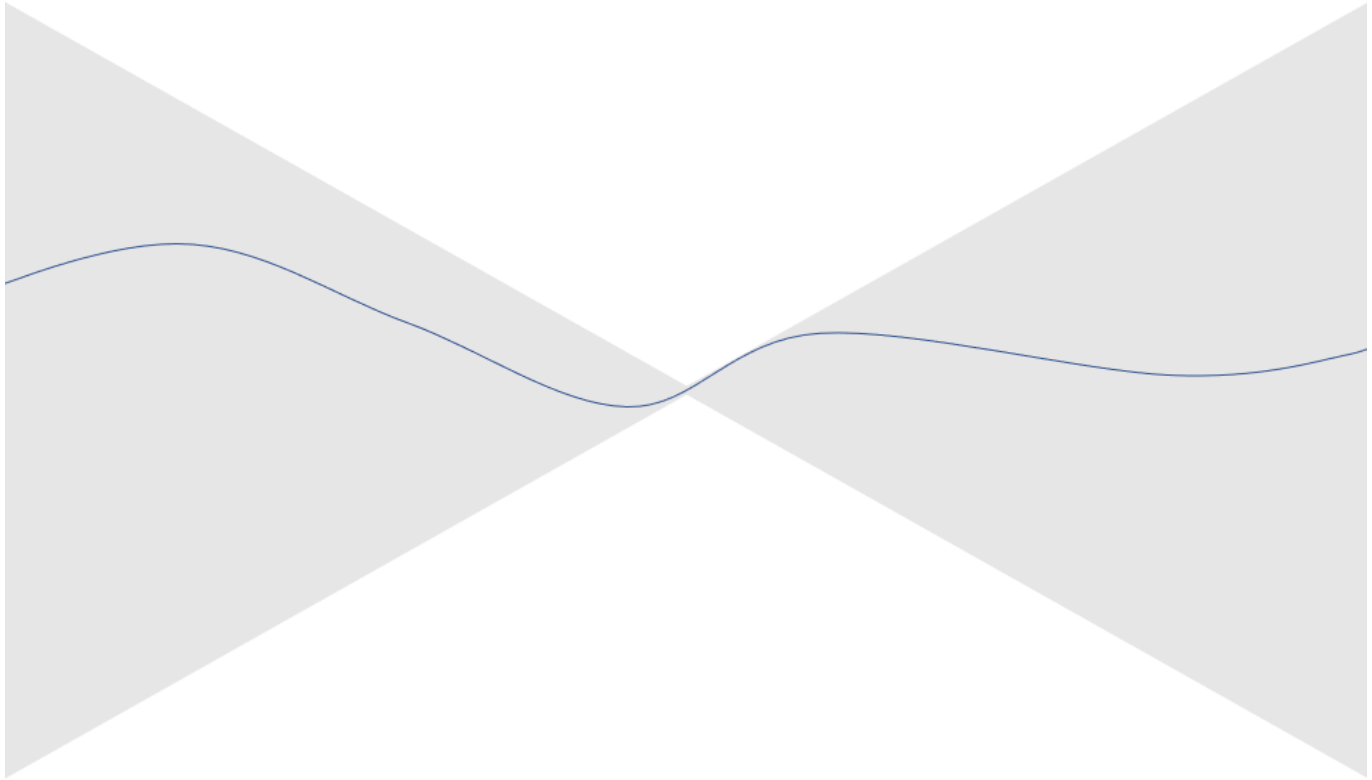
- *In cyclic BAGs, algorithm may not converge (Mossakowski, Neuhaus 2018)*





Mossakowski, T., & Neuhaus, F.. Modular semantics and characteristics for bipolar weighted argumentation graphs. *arXiv preprint arXiv:1807.06685*. 2018.

Digression: Lipschitz Continuity



- Lipschitz-continuous: *„function does not grow faster than some linear function"*

there is some λ such that $| f(x_1) - f(x_2) | \leq \lambda \times |x_1 - x_2|$ *for all* x_1, x_2

- *λ 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 λ_1,
2. influence function has Lipschitz-constant λ_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

Mossakowski, T., & Neuhaus, F.. Modular semantics and characteristics for bipolar weighted argumentation graphs. *arXiv preprint arXiv:1807.06685*. 2018.
Potyka, N. Extending Modular Semantics for Bipolar Weighted Argumentation. In Proceedings of the 18th International Conference on Autonomous Agents and MultiAgent Systems (AAMAS 2019*)*. 2019.

Some Lipschitz Constants

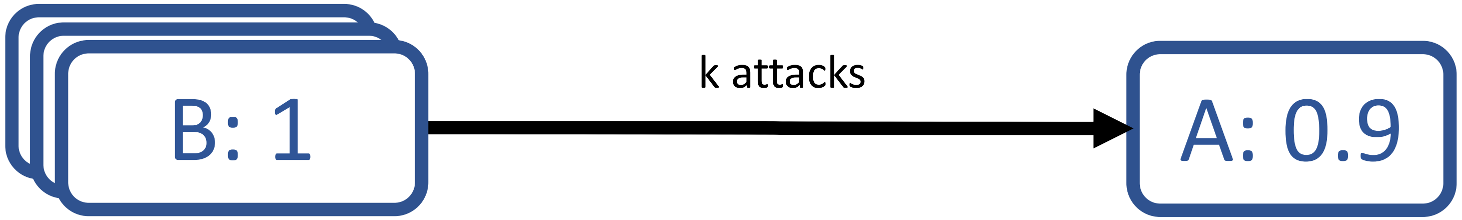
Aggregation Function	λ
Product	max. indegree of any argument in BAG
Sum	max. indegree of any argument in BAG
Top	≤2

Influence Function	λ
Linear(k)	$\frac{1}{k}\max\ \{w(i), 1\ - w(i) : i = 1, \dots, n\}$
Euler-based	0.25
qmax(k)	$\frac{1}{k}\max\ \{w(i), 1\ - w(i) : i = 1, \dots, n\}$

Some Convergence Guarantees

Semantics	Aggregation	Influence	Sufficient Conditions
(Mossakowski, Neuhaus 2018)	Top	Euler-based	Always
DF-QuAD (k=1)	Product	Linear(k)	Max. indegree < k
Euler-based	Sum	Euler-based	Max. indegree < 4
Quadratic Energy (k=1)	Sum	qmax(k)	Max. indegree $< k$

Convergence Guarantees vs. Open-Mindedness



Aggregation	Influence	k=0	k=1	k=10	k=100
Top	Euler	0.9	0.862	0.862	0.862
Addition	Euler	0.9	0.862	0.811	0.811
Top	qmax(1)	0.9	0.498	0.498	0.498
Addition	qmax(1)	0.9	0.498	0.012	0.001
Top	qmax(5)	0.9	0.873	0.873	0.873
Addition	qmax(5)	0.9	0.873	0.213	0.004

Convergence Guarantees vs. Open-Mindedness

Lemma (AAMAS 2019)
If semantics is defined by
1. aggregation function that maps to [-B, B],
2. combination function with Lipschitz-constant λ,

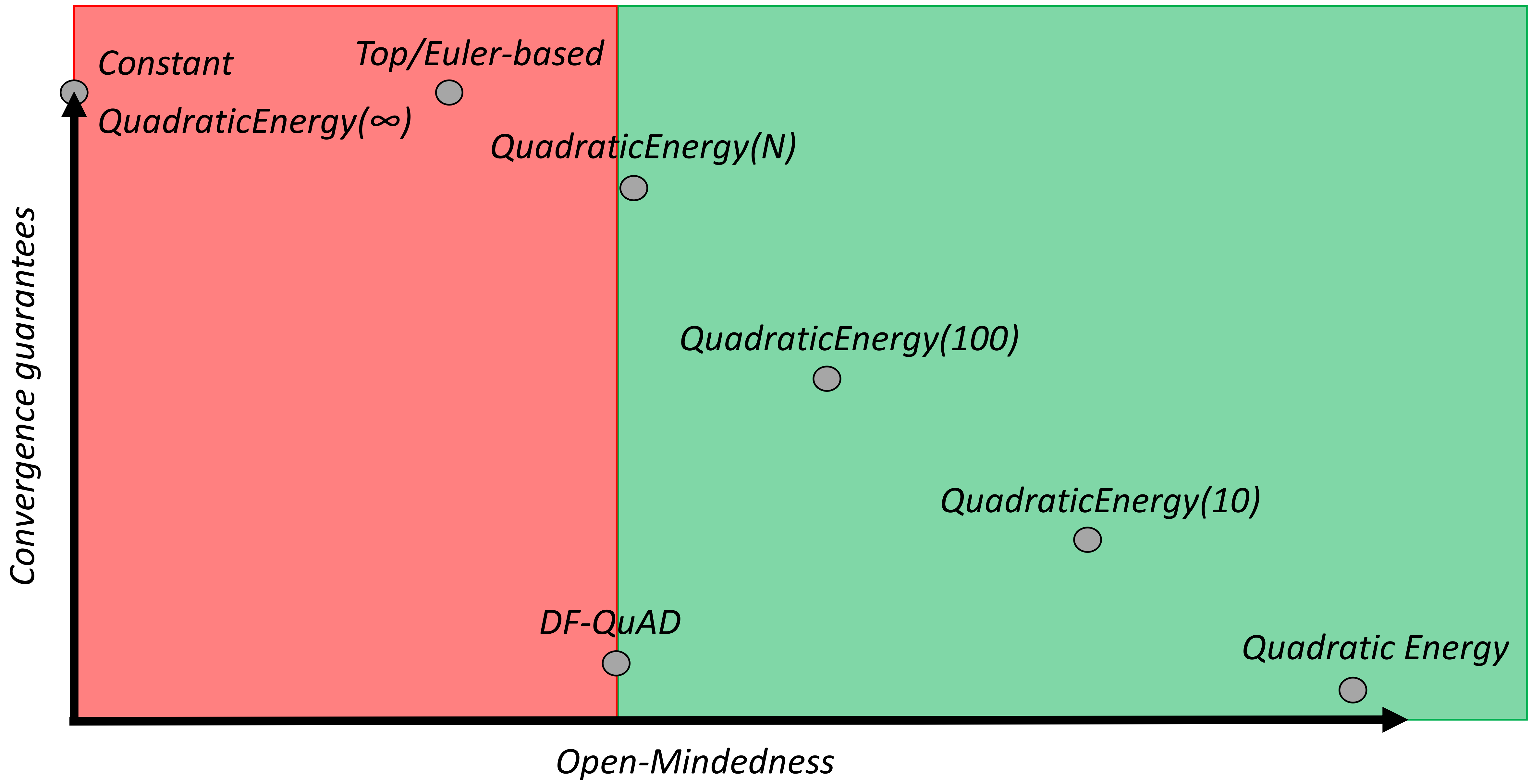
then $|s(i) - w(i)| \leq \lambda \times B$.

Aggregation Function	Range
Product	[-1, 1]
Sum	(-∞, ∞)
Top	[-1, 1]

Influence Function	λ
Linear(k)	$\geq \frac{1}{k}$
Euler-based	$\frac{1}{4}$
qmax(k)	$\geq \frac{1}{k}$

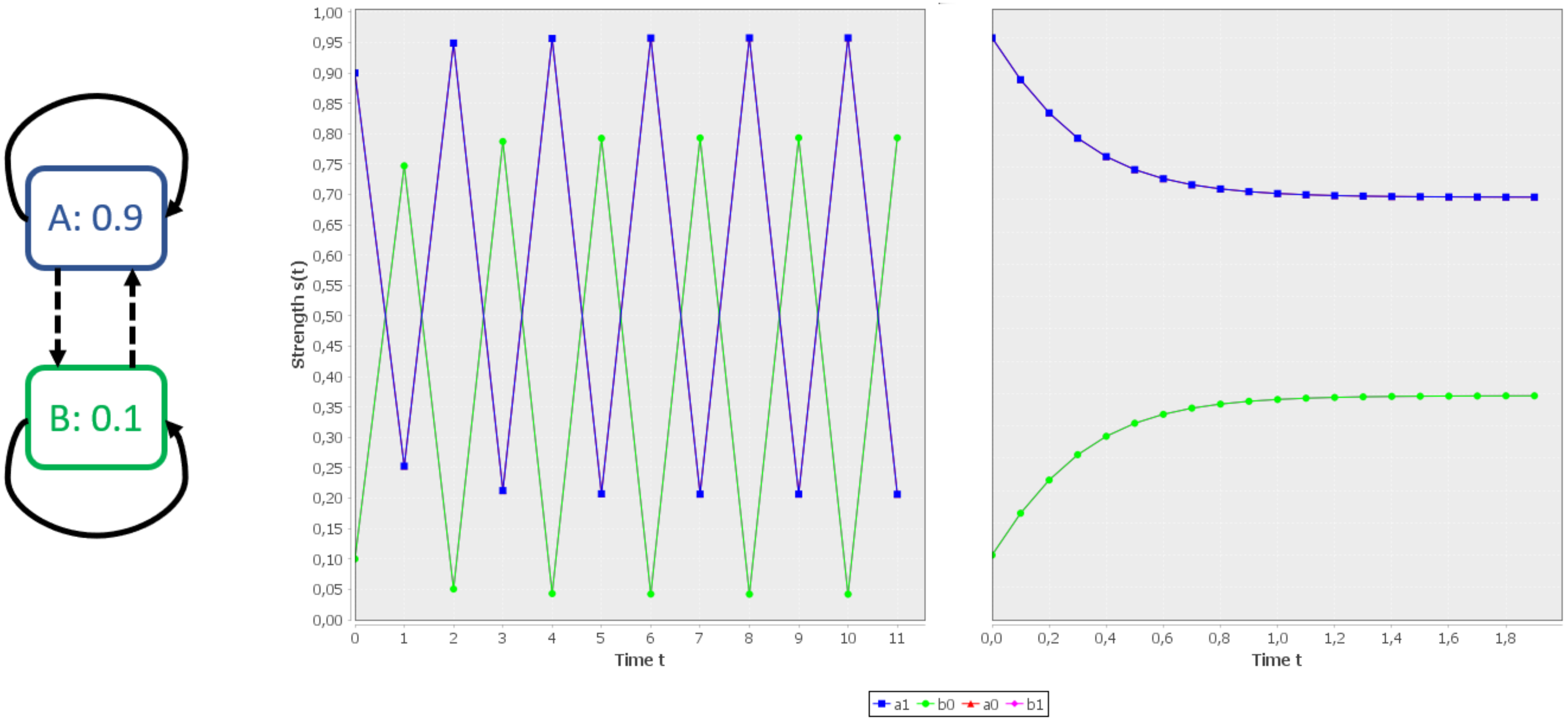
Potyka, N. Extending Modular Semantics for Bipolar Weighted Argumentation. In Proceedings of the 18th International Conference on Autonomous Agents and MultiAgent Systems (AAMAS 2019). 2019.

Convergence Guarantees vs. Open-Mindedness



Improving Guarantees by Continuization

- *(Discrete) semantics can be seen as coarse approximations of continuous semantics*
- *Continuizing semantics can solve divergence problems without loosing open-mindedness*

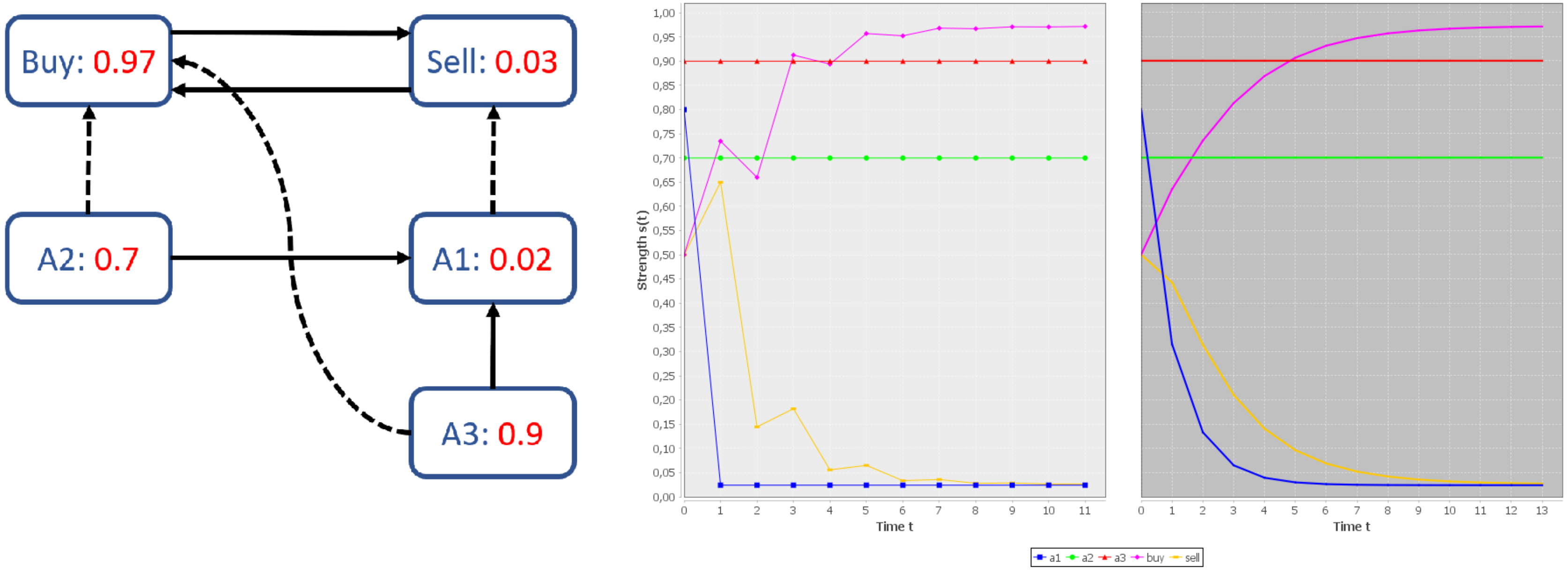


Potyka, N. Continuous dynamical systems for weighted bipolar argumentation. In *Sixteenth International Conference on Principles of Knowledge Representation and Reasoning (KR 2018)*. 2018.

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.



Potyka, N. Extending Modular Semantics for Bipolar Weighted Argumentation. In Proceedings of the 18th International Conference on Autonomous Agents and MultiAgent Systems (AAMAS 2019). 2019.

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)*

Potyka, N. Extending Modular Semantics for Bipolar Weighted Argumentation. In Proceedings of the 18th International Conference on Autonomous Agents and MultiAgent Systems (AAMAS 2019*)*. 2019.

Some Further Readings about Computational Issues

- *Fixed points in Social Abstract Argumentation*

Leite, J., & Martins, J. Social abstract argumentation. In Twenty-Second International Joint Conference on Artificial Intelligence (IJCAI 2011). 2011.

Amgoud, L. et al. A note on the uniqueness of models in social abstract argumentation. arXiv preprint arXiv:1705.03381.

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

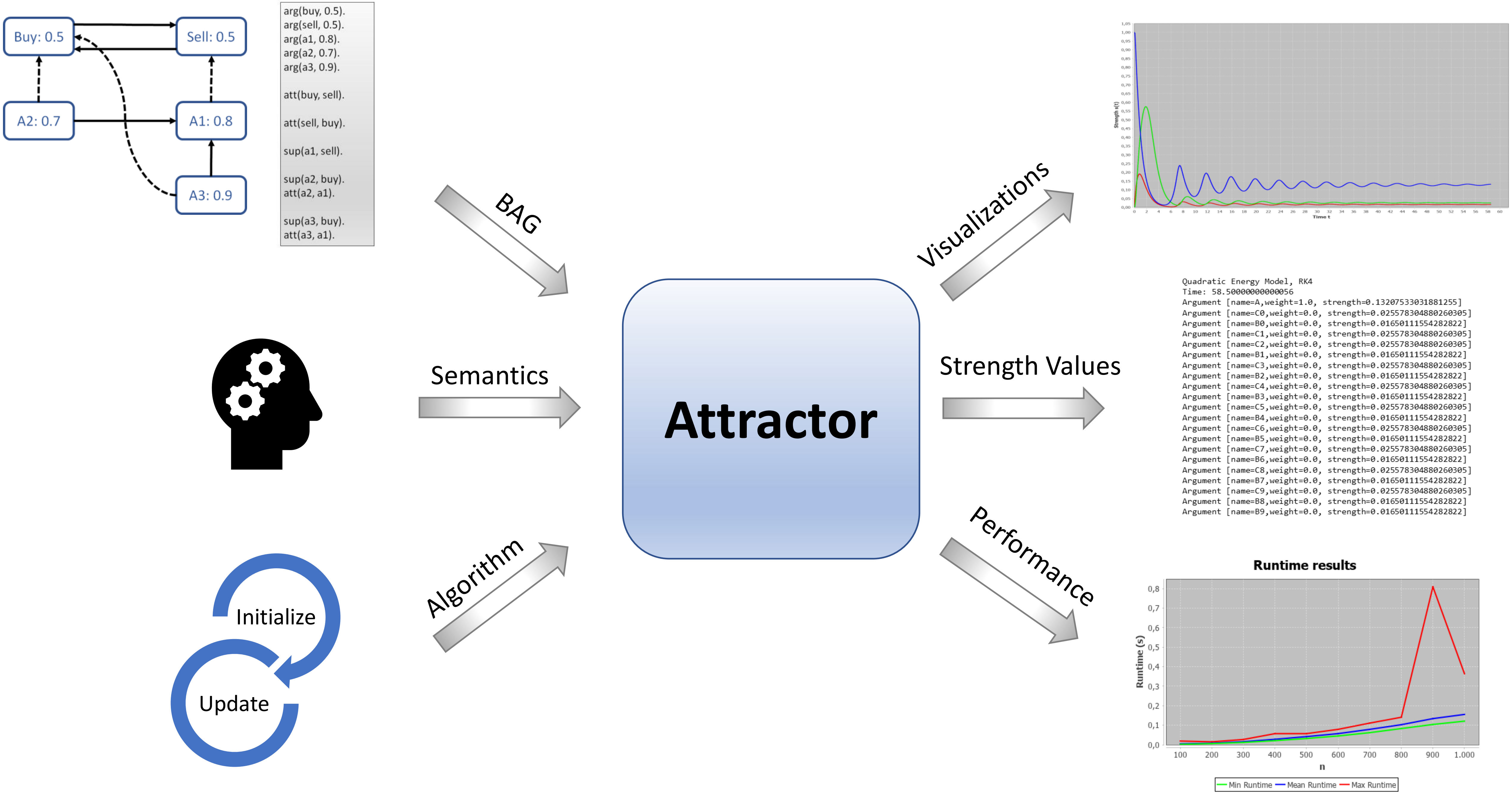
Amgoud, L., & Doder, D. Gradual Semantics Accounting for Varied-Strength Attacks. In Proceedings of the 18th International Conference on Autonomous Agents and MultiAgent Systems (AAMAS 2019). 2019.

- *High-Level Introduction to Continuous Semantics*

Potyka, N. (2018). A Tutorial for Weighted Bipolar Argumentation with Continuous Dynamical Systems and the Java Library Attractor. 17th International Workshop on Non-Monotonic Reasoning (NMR 2018). 2018.

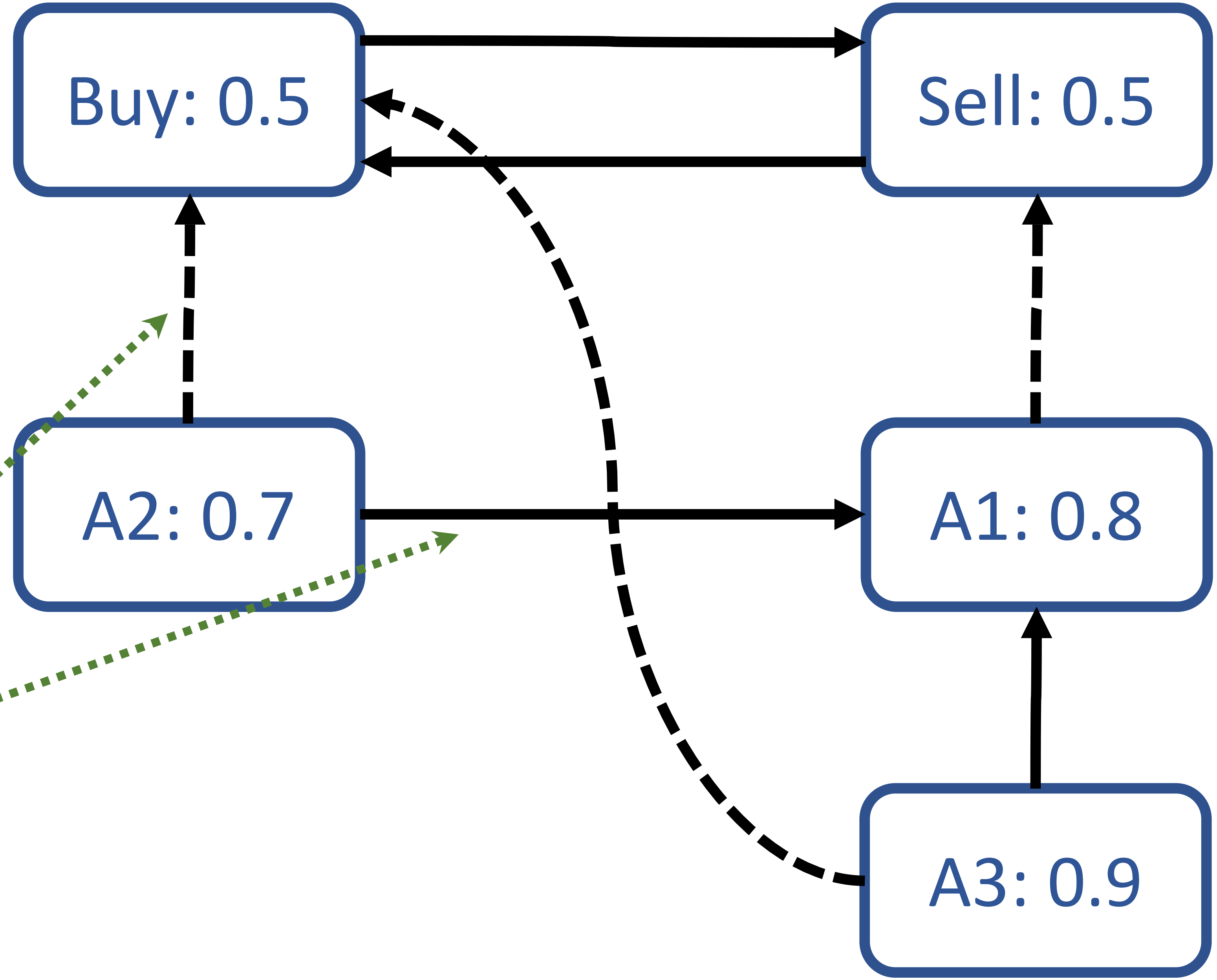
Gradual Bipolar Argumentation

Programming with 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).
```



Solving Weighted Argumentation Problems

```
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();
}
```

Select Semantics

Select Algorithm

Use utility tools to read BAG

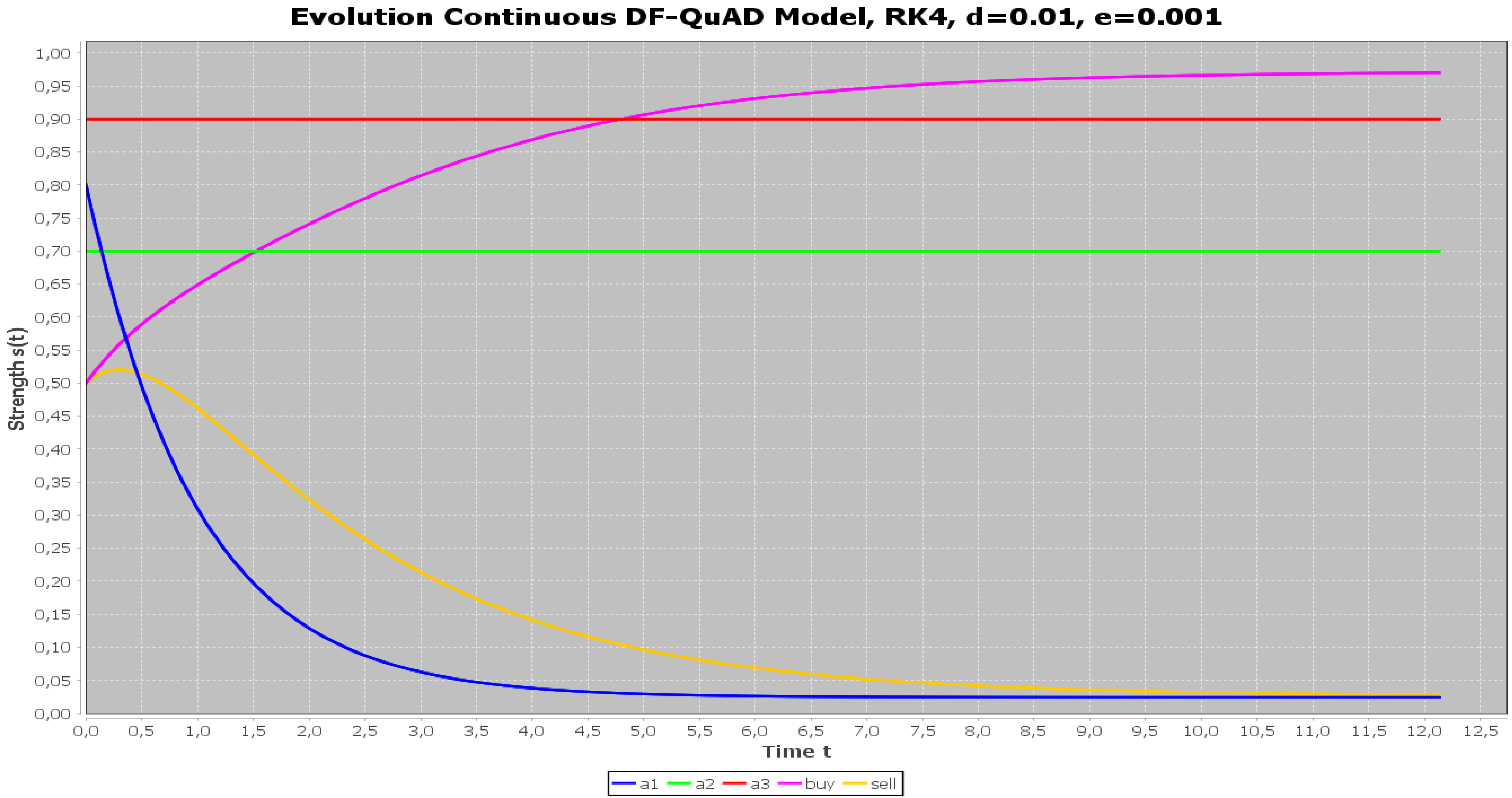
Step size

ε

Info

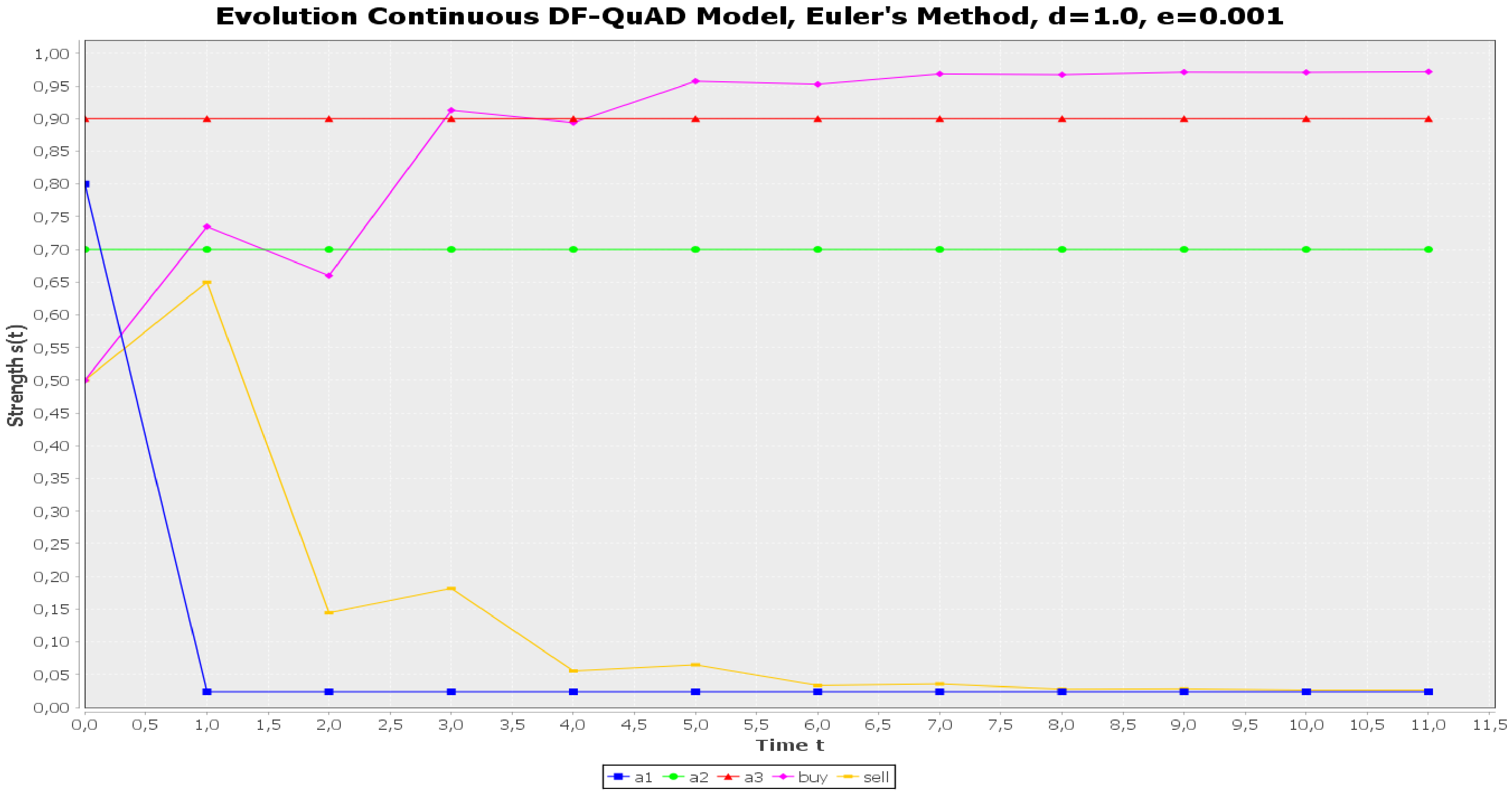
```
ads.setApproximator(new PlottingRK4(ads));
ads.approximateSolution(10e-3, 10e-4, true);
```

Generate visualizations with JFreeChart



```
ads.setApproximator(new PlottingEulersMethod(ads));
ads.approximateSolution(1, 10e-4, true);
```

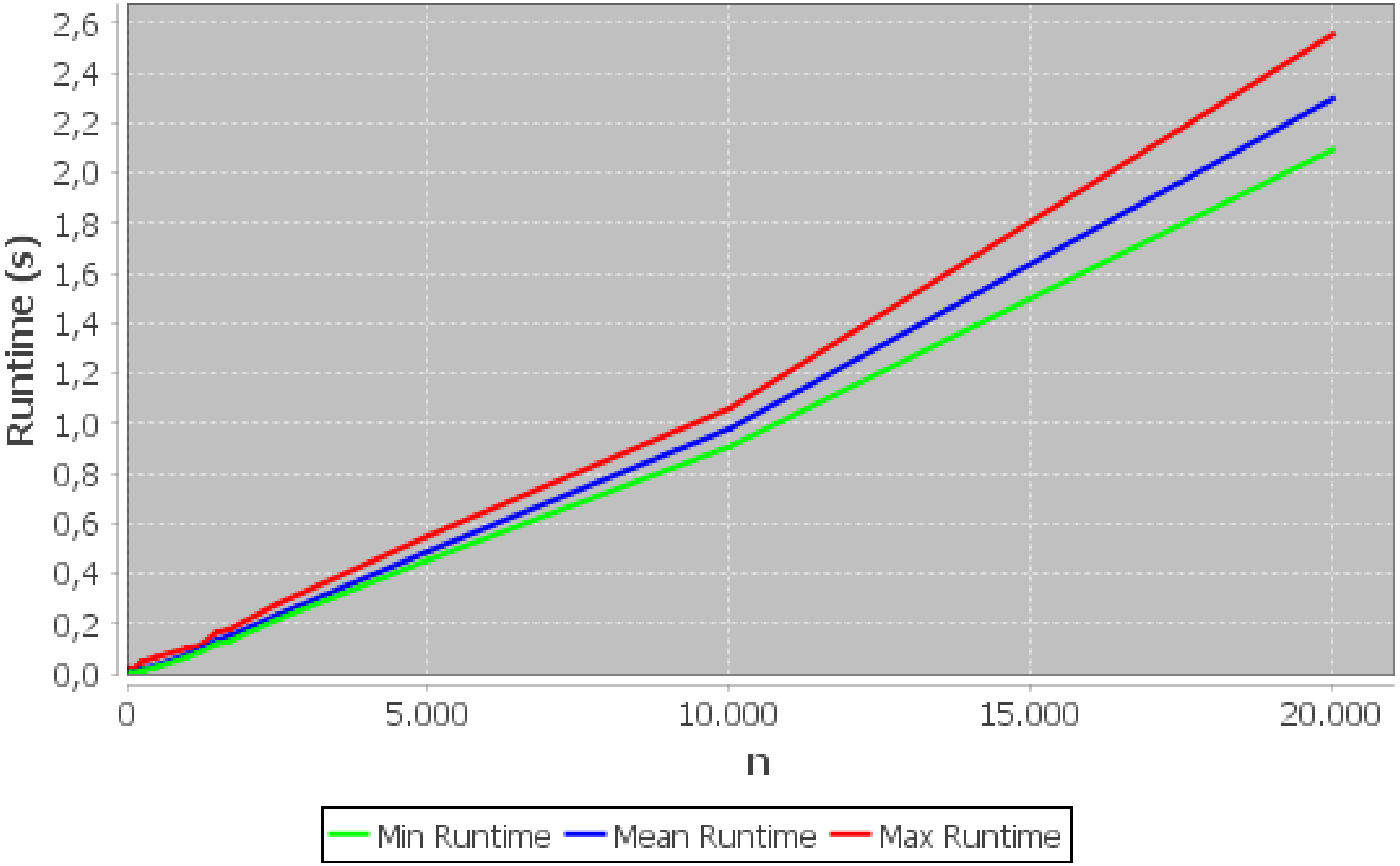
Simulate Discrete Semantics using Euler‘s Method (KR 2018)



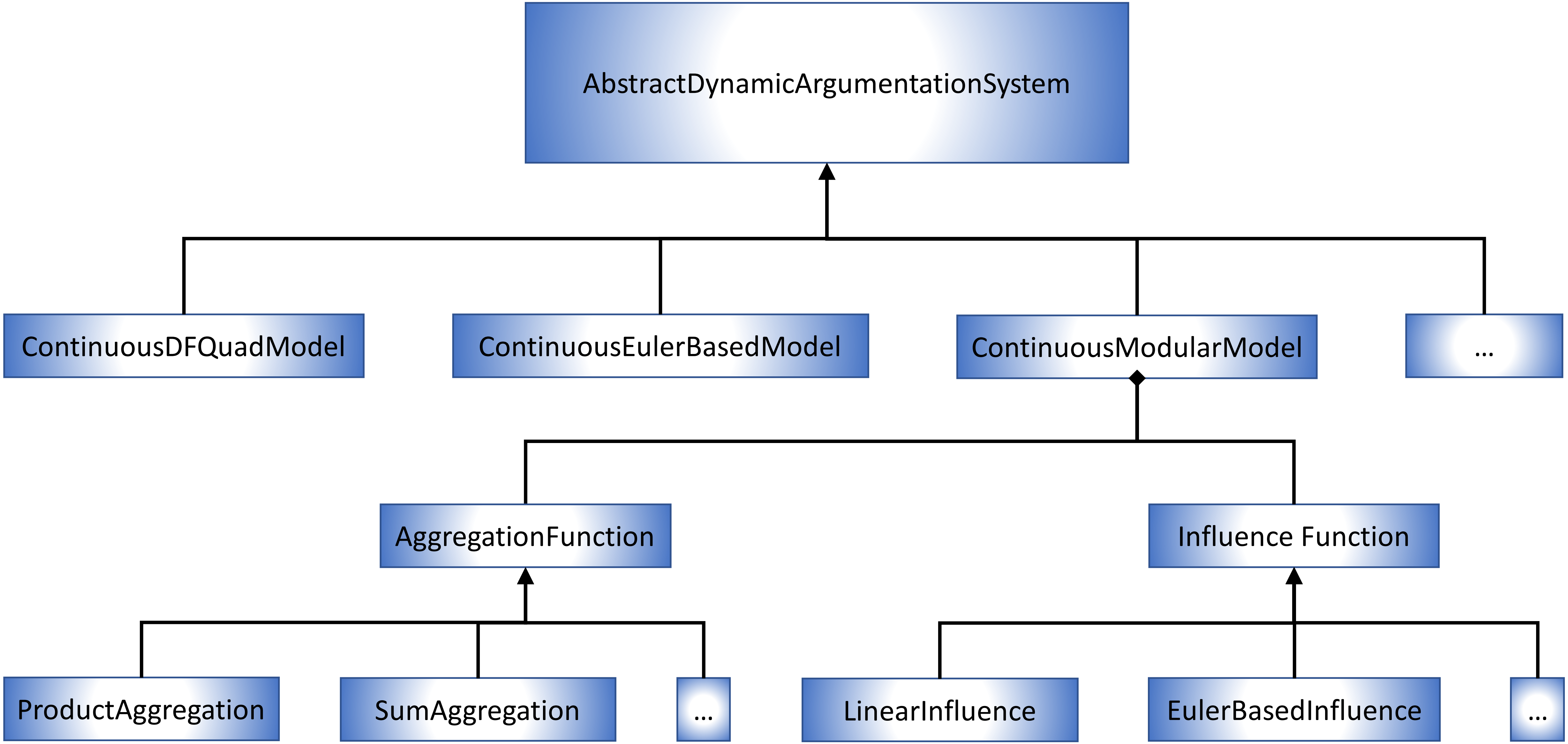
Potyka, N. Continuous dynamical systems for weighted bipolar argumentation. In *Sixteenth International Conference on Principles of Knowledge Representation and Reasoning (KR 2018)*. 2018.

```
BenchmarkUtils benchmark = new BenchmarkUtils();
File benchmarkDirectory = new File("files/networks/barabasi");
QuadraticEnergyModel qas = new QuadraticEnergyModel();

benchmark.runBenchmark(benchmarkDirectory, qas);
```

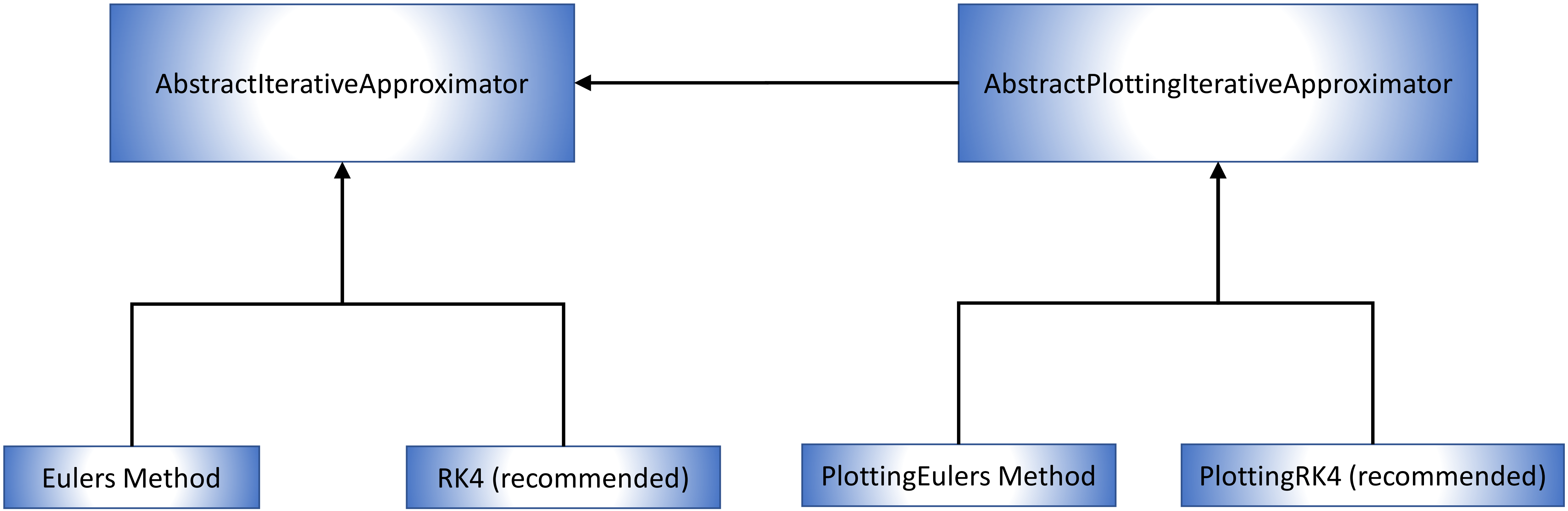
Perform Benchmarks



Using and Adding Semantics



Using and Adding Algorithms



Documentation

- *Tutorial Article*

Potyka, N. (2018). A Tutorial for Weighted Bipolar Argumentation with Continuous Dynamical Systems and the Java Library Attractor. 17th International Workshop on Non-Monotonic Reasoning (NMR 2018). 2018.

- *Javadoc*

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

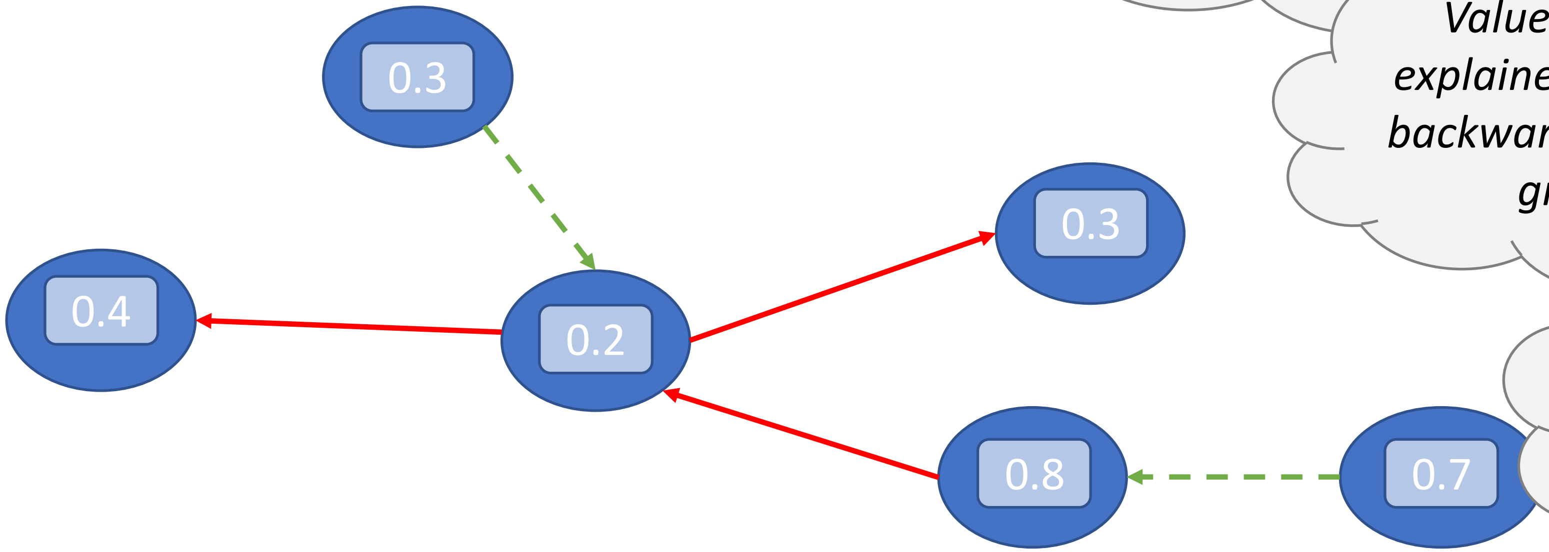
Summary

Summary

Quantitative AAFs assign numerical values (belief, strength) to arguments

Values can be explained by going backwards through graph

Rules can be used to generate simple automated explanation dialogues



Summary

- Probabilistic Epistemic Argumentation
- Evaluation: probabilities
- Complexity: (polynomial)
- Model
  - Bipolar Argumentation Graph
  - Semantical Constraints
- Implementation *https://sourceforge.net/projects/probabble/*

Hunter, A., & Thimm, M. (2014). Probabilistic Argumentation with Incomplete Information. In European Conference on Artificial Intelligence (*ECAI*): 1033-1034.

- Gradual Bipolar Argumentation
- Evaluation: strength values
- Complexity: (polynomial)
- Model
  - Bipolar Argumentation Graph
  - Initial Weights
  - Update function
- Implementation *https://sourceforge.net/projects/attractorproject/*

Baroni, P., Rago, A., & Toni, F. (2018). How many properties do we need for gradual argumentation?. In *Thirty-Second AAAI Conference on Artificial Intelligence (AAAI): 1736-1743*.