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Controllability of Control Argumentation Frameworks

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Motivation: The study of **computational models of argumentation** is an active and vibrant area of modern **AI** research
Control argumentation frameworks recently proposed formalism for **reasoning under uncertainty**
Computational complexity of controllability not established, no system implementation available

Contributions: Complete **complexity** map of credulous and skeptical **controllability** under five central AF semantics
Design of algorithms for solving controllability: QBF encodings and SAT-based CEGAR algorithms
System implementation and empirical evaluation: approaches are complementary

CONTROL ARGUMENTATION FRAMEWORKS

Argumentation Framework (AF)

A directed graph $AF = (A, R)$:

- A is the set of **arguments**
- $R \subseteq A \times A$ is the **attack relation**

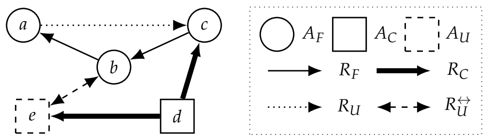
Semantics σ **define** σ**-extensions**

- jointly acceptable sets of arguments
- required to be **conflict-free**
- other desired properties give rise to different semantics: admissible, complete, preferred, stable, grounded

Control Argumentation Framework (CAF)

An AF with three parts:

- (A_F, R_F): **fixed** part
- $(A_U, R_U, R_U^{\leftrightarrow})$: **uncertain** part
- (A_C, R_C): **control** part



Example control argumentation framework.

Controllability

Control configuration: subset of arguments $A_{conf} \subseteq A_C$
Completion: standard AF with the fixed part, the control configuration, and any uncertain elements

SKEPTICAL CONTROLLABILITY

Is there a **control configuration** such that for all **completions**, target set $T \subseteq A_F$ is included in **every** σ-extension?

COMPUTATIONAL COMPLEXITY OF CONTROLLABILITY

	General CAFs		Simplified CAFs	
Semantics	Credulous	Skeptical	Credulous	Skeptical
admissible	Σ_3^P-c	trivial	NP-c	trivial
complete	Σ_3^P-c	Σ_2^P-c	NP-c	NP-c
preferred	Σ_3^P-c	Σ_3^P-c	NP-c	Σ_3^P-c
stable	Σ_3^P-c	Σ_2^P-c	NP-c	Σ_2^P-c
grounded	Σ_2^P-c	Σ_2^P-c	NP-c	NP-c

- Controllability in **simplified CAFs** corresponds to possible acceptance in **incomplete AFs**
  - Simplified CAF: no uncertain part
  - Reduction from possible acceptance
- Some hardness results for **general CAFs** follow from hardness in **simplified CAFs**
  - The rest via reduction from QBF (**in paper**)

ALGORITHMS FOR SOLVING CONTROLLABILITY

Input: Control AF CAF, target set $T \subseteq A_F$.

Basis: SAT Encodings

Boolean variables:

- y_a for each argument a, $r_{a,b}$ for each attack (a, b)
  - true iff element included in completion
- x_a for each argument a
  - true iff argument included in σ-extension

Propositional formulas:

- $\varphi_?(CAF)$ encodes control configurations and completions
- $\varphi_\sigma(CAF)$ for $\sigma \in \{adm, com, stb\}$ encodes the semantics

QBF Encodings

Task: Skeptical controllability under $\sigma \in \{com, stb\}$.
Quantifier blocks: $X = \{y_a \mid a \in A_C\}$, $Y = \{y_a \mid a \in A_U\} \cup \{r_{a,b} \mid (a,b) \in R_U \cup R_U^{\leftrightarrow}\} \cup \{x_a \mid a \in A_F \cup A_U \cup A_C\}$
2-QBF:

$$\forall X \exists Y \left(\varphi_?(CAF) \land \varphi_\sigma(CAF) \land \bigvee_{t \in T} \neg x_t \right)$$

false iff CAF is skeptically controllable under σ

SAT-based CEGAR Algorithms

Algorithms where a **SAT solver** is **called iteratively** and incrementally using different assumptions.
Task: Skeptical controllability under $\sigma = com$.

$\varphi \leftarrow \varphi_?(CAF) \land \varphi_{com}(CAF)$ ▷ Initialize abstraction
while true do
  $(result, \tau) \leftarrow \text{SAT}(\varphi \land \bigwedge_{t \in T} x_t)$ ▷ Solve abstraction
  if $result = unsat$ **then return** $reject$
  $(result, \tau) \leftarrow \text{SAT}(\varphi \land \psi(A_{conf}^\tau) \land \bigvee_{t \in T} \neg x_t)$ ▷ C.E.?
  if $result = unsat$ **then return** A_{conf}^τ
  $\varphi \leftarrow \varphi \land \text{REFINE}(A_{conf}^\tau)$ ▷ Exclude configuration
end while

Strong refinement: take into account which atomic changes preserve the counterexample extension of the completion

For $\sigma = stb$: instead of direct *reject*: is there a configuration without a completion with a stable extension?

In paper: 3-QBF and SAT-based CEGAR algorithm for credulous controllability under $\sigma \in \{adm, stb\}$

EMPIRICAL EVALUATION

Implementation: TAEYDENNAE

- Solver for incomplete and control AFs
- SAT-based CEGAR algorithms + QDIMACS output
- Available online in open source:

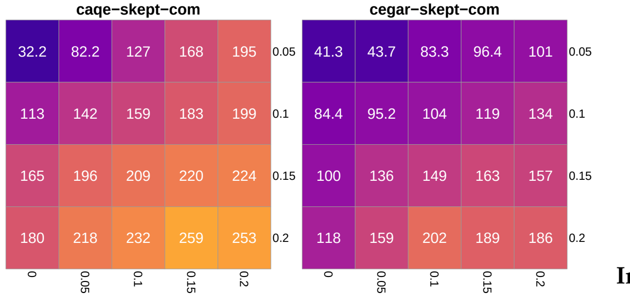
`bitbucket.org/andreasniskanen/taeydennae`

Benchmark instances

6250 control AFs generated from ICCMA'19 AFs

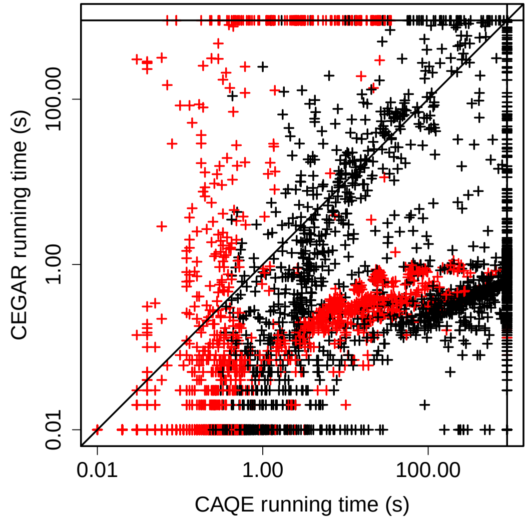
- p_C, four values in $[0.05, 0.2]$: prob. of control argument
- p_U, five values in $[0, 0.02]$: prob. of uncertain element

Mean solving times: p_U on rows, p_C on columns



Task: Skeptical controllability under $\sigma = com$

SAT-based CEGAR vs. QBF solver CAQE:



In paper: Empirical results for other variants

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