Splitting Abstract Dialectical Frameworks

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FWF
Der Wissenschaftsfonds.
Abstract Dialectical Frameworks (ADFs) [Brewka and Woltran, 2010]
- Generalization of Abstract Argumentation Frameworks [Dung, 1995]
- Acceptance condition for each argument

Provide high modelling power
- Support, set attack, set support, ...
- Acceptance as an arbitrary Boolean function
Introduction

- Abstract Dialectical Frameworks (ADFs) [Brewka and Woltran, 2010]
  - Generalization of Abstract Argumentation Frameworks [Dung, 1995]
  - Acceptance condition for each argument
- Provide high modelling power
  - Support, set attack, set support, . . .
  - Acceptance as an arbitrary Boolean function
- ADFs can capture many AF-generalizations
  - Translations to ADFs [Polberg, 2014]
  - SETAF [Nielsen and Parsons, 2006], AFN [Nouioua and Risch, 2011], AFRA [Baroni et al., 2011], EAF [Modgil, 2009], . . .
  - Efficient solvers for ADFs beneficial for argumentation in general
- Instantiation of defeasible theory bases satisfying rationality postulates [Strass, 2013]
Splitting: Optimization technique allowing to incrementally compute the results under a given semantics.

Properties of semantics which can be exploited in implementations of reasoning tasks within ADFs.
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Properties of semantics which can be exploited in implementations of reasoning tasks within ADFs.

Directional Splitting: Positive results for all standard semantics defined in [Brewka et al., 2013].

General Splitting: Preliminary results for models and admissible interpretations.

Completing the picture of relations between semantics.
Motivation

- Optimization in implementation of ADFs.
  - Hardness of reasoning tasks up to $\sum_3^P$.
  - Splitting into smaller instances.
  - Reduction of search space.

Abstract Argumentation Frameworks [Baumann, 2011].
Logic Programs [Lifschitz and Turner, 1994].
Motivation

- Optimization in implementation of ADFs.
  - Hardness of reasoning tasks up to $\Sigma^P_3$.
  - Splitting into smaller instances.
  - Reduction of search space.
- Dynamic aspects.
  - Additional information and/or revised knowledge.
  - Possibility to reuse partial results.
  - Only deal with the changed part.
Motivation

- Optimization in implementation of ADFs.
  - Hardness of reasoning tasks up to $\Sigma_3^P$.
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- Common technique in nonmonotonic formalisms.
  - Abstract Argumentation Frameworks [Baumann, 2011].
  - Logic Programs [Lifschitz and Turner, 1994].
An ADF is a tuple $D = (A, L, C)$ where

- $A$ is a set of arguments (statements, positions),
- $L \subseteq A \times A$ is a set of links, and
- $C = \{ C_a \mid a \in A \}$ is a set of total functions $C_a : 2^a_D \mapsto \{ t, f \}$, with $a_D^- = \{ b \in A \mid (b, a) \in L \}$. $C_a$ is called acceptance condition of $a$.

We will use propositional (acceptance) formulas $\varphi_a$ as acceptance conditions of an argument $a$.

Atoms in acceptance formulas determine ingoing links: ADF may be represented as $\{ \langle a, \varphi_a \rangle \mid a \in A \}$. 
Background

\[ D = \{ \langle a, \neg b \rangle, \langle b, \neg a \rangle, \langle c, \neg b \land d \rangle, \langle d, c \rangle \} \]
$$D = \{ \langle a, \neg b \rangle, \langle b, \neg a \rangle, \langle c, \neg b \land d \rangle, \langle d, c \rangle \}$$

- $$A_D = \{ a, b, c, d \}.$$
Background

\[ D = \{\langle a, \neg b \rangle, \langle b, \neg a \rangle, \langle c, \neg b \land d \rangle, \langle d, c \rangle \} \]

- \( A_D = \{a, b, c, d\} \).
- \( L_D = \{(b, a), (a, b), (b, c), (d, c), (c, d)\} \).
Background

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- \( A_D = \{ a, b, c, d \} \).
- \( L_D = \{ (b, a), (a, b), (b, c), (d, c), (c, d) \} \).

\[ D|_B = \{ \langle a, \varphi_a \rangle \in D \mid a \in B \} \]
Background

\[ D = \{ \langle a, \neg b \rangle, \langle b, \neg a \rangle, \langle c, \neg b \land d \rangle, \langle d, c \rangle \} \]

- \( A_D = \{ a, b, c, d \} \).
- \( L_D = \{ (b, a), (a, b), (b, c), (d, c), (c, d) \} \).

\[ D\mid_B = \{ \langle a, \varphi_a \rangle \in D \mid a \in B \} \]
\[ D\mid_{\{a,b\}} = \{ \langle a, \neg b \rangle, \langle b, \neg a \rangle \} \].
Background

Definition

Given an ADF $D$, an interpretation is a mapping $v : A_D \mapsto \{t, f, u\}$. We denote $v^x = \{a \in A_D \mid v(a) = x\}$ for $x \in \{t, f, u\}$. The interpretation $v$ is two-valued if $v^u = \emptyset$.

Partial order $\leq_i$ on truth values: $u <_i t$ and $u <_i f$.

Given ADF $D$,

- $v_1 \leq_i v_2$ iff $v_1(a) \leq_i v_2(a)$ for all $a \in A_D$.
- $[v]_2$ denotes the set of two-valued interpretations $w$ with $v \leq_i w$. 
Background

Definition

Given an ADF $D$ and an interpretation $\nu$, the characteristic function $\Gamma_D(\nu) = \nu'$ is defined as

$$\nu'(a) = \begin{cases} 
  \text{t} & \text{if } w(\varphi_a) = \text{t} \text{ for all } w \in [\nu]_2 \\
  \text{f} & \text{if } w(\varphi_a) = \text{f} \text{ for all } w \in [\nu]_2 \\
  \text{u} & \text{otherwise}
\end{cases}$$
Definition [Brewka et al., 2013]

Given an ADF $D$, a three-valued interpretation $v$ is

- a model of $D$ iff $v^u = \emptyset$ and for all $a \in A_D$, $v(a) = v(\varphi_a)$,
- a three-valued model of $D$ iff for all $a \in A_D$, $v(a) \neq u$ implies $v(a) = v(\varphi_a)$,
- an admissible interpretation of $D$ iff $v \leq_i \Gamma_D(v)$,
- a preferred interpretation of $D$ iff $v$ is a $\leq_i$-maximal admissible interpretation of $D$,
- a complete interpretation of $D$ iff $v = \Gamma_D(v)$,
- the grounded interpretation of $D$ iff $v$ is the least fixpoint of $\Gamma_D$ wrt. $\leq_i$,
- a stable model of $D$ iff $v$ is a model of $D$ and $v^t = w^t$, with $w$ being the grounded interpretation of $D^{v^-} = \{ \langle a, \varphi_a[x/\bot] : v(x) = f \rangle \mid a \in v^t \}$. 

Background

Example

\[ \neg b \quad \neg a \quad \neg b \land d \quad c \]

\[ \text{mod}_2(D) = \text{pref}(D) = \{ \}
\]
Example

\[ \neg b \quad \neg a \quad \neg b \land d \quad c \]

\[ a \rightarrow b \rightarrow c \rightarrow d \]

\[ \text{mod}_2(D) = \text{pref}(D) = \{ a \mapsto t, b \mapsto f, c \mapsto f, d \mapsto f \}, \]
Example

\[ \neg b \quad \neg a \quad \neg b \land d \quad c \]

\[ a \quad b \quad c \quad d \]

\[ \text{mod}_2(D) = \text{pref}(D) = \{ \{ a \mapsto t, b \mapsto f, c \mapsto f, d \mapsto f \}, \{ a \mapsto f, b \mapsto t, c \mapsto f, d \mapsto f \} \}, \]
Background

Example

\[ \neg b \quad \neg a \quad \neg b \land d \quad c \]

\[ \text{mod}_2(D) = \text{pref}(D) = \begin{cases} \{ a \mapsto \text{t}, b \mapsto \text{f}, c \mapsto \text{f}, d \mapsto \text{f}\} , \\ \{ a \mapsto \text{f}, b \mapsto \text{t}, c \mapsto \text{f}, d \mapsto \text{f} \} , \\ \{ a \mapsto \text{t}, b \mapsto \text{f}, c \mapsto \text{t}, d \mapsto \text{t} \} \end{cases} \]
Definition

Let $G_1 = (A_1, L_1)$ and $G_2 = (A_2, L_2)$ be directed graphs such that $A_1 \cap A_2 = \emptyset$ and let $L_3 \subseteq A_1 \times A_2$. The tuple $(G_1, G_2, L_3)$ is a directional splitting of an ADF $D = (A_1 \cup A_2, L_1 \cup L_2 \cup L_3, C)$. 
Directional Splitting

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\[ \neg b \]

\[ \neg a \lor b \]

\[ \neg a \]

\[ \neg c \lor \neg e \]

\[ (c \lor d) \land \neg f \]

\[ \neg d \]

\[ \neg c \lor \neg e \]

\[ \neg d \]

\[ (c \lor d) \land \neg f \]
Definition

Let $G_1 = (A_1, L_1)$ and $G_2 = (A_2, L_2)$ be directed graphs such that $A_1 \cap A_2 = \emptyset$ and let $L_3 \subseteq A_1 \times A_2$. The tuple $(G_1, G_2, L_3)$ is a directional splitting of an ADF $D = (A_1 \cup A_2, L_1 \cup L_2 \cup L_3, C)$. 
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Definition

Let $G_1 = (A_1, L_1)$ and $G_2 = (A_2, L_2)$ be directed graphs such that $(G_1, G_2, L_3)$ is a directional splitting of the ADF $D$ and let $v$ be an interpretation of $D|_{A_1}$. The $v$-reduct of $D$ is defined as

$$D^v = \{ \langle a, \varphi_a[b/v(b) : b \in (v^t \cup v^f)][c/x_c : c \in v^u] \rangle \mid a \in A_2 \} \cup \{ \langle x_c, \neg x_c \rangle \mid c \in v^u \}.$$
Directional Splitting

Definition

Let $G_1 = (A_1, L_1)$ and $G_2 = (A_2, L_2)$ be directed graphs such that $(G_1, G_2, L_3)$ is a directional splitting of the ADF $D$ and let $\nu$ be an interpretation of $D|_{A_1}$. The \nu-reduct of $D$ is defined as

$$D^{\nu} = \{ \langle a, \varphi_a[b/\nu(b) : b \in (\nu^t \cup \nu^f)][c/x_c : c \in \nu^u] \rangle | a \in A_2 \} \cup \{ \langle x_c, \neg x_c \rangle | c \in \nu^u \}.$$

Theorem

Let $\sigma \in \{mod_2, mod_3, adm, pref, comp, grd, stb\}$, and $G_1 = (A_1, L_1)$ and $G_2 = (A_2, L_2)$ be directed graphs such that $(G_1, G_2, L_3)$ is a directional splitting of the ADF $D$. Further let $D_1 = D|_{A_1}$. It holds that

1. $\nu_1 \in \sigma(D_1) \land \nu_2 \in \sigma(D^{\nu_1}) \Rightarrow (\nu_1 \cup \nu_2)|_A \in \sigma(D),$
2. $\nu \in \sigma(D) \Rightarrow \nu|_{A_1} \in \sigma(D_1) \land \exists \nu_2 \in \sigma(D^{\nu|_{A_1}}) : \nu_2|_{A_2} = \nu|_{A_2}.$
Directional Splitting – Procedure

\[ \neg b \quad \neg a \lor b \quad \neg c \lor \neg e \quad \neg d \]

\[ \neg a \quad (c \lor d) \land \neg f \]

\[ \text{pref}(D) = \{ \} \]
Directional Splitting – Procedure

\[ \neg b \]
\[ \neg a \vee b \]
\[ \neg c \vee \neg e \]
\[ (c \vee d) \wedge \neg f \]

\[ \text{pref}(D) = \{ \]
Directional Splitting – Procedure

\[ \neg a \lor b \quad (c \lor d) \land \neg f \]

\[ \neg b \quad \neg c \lor \neg e \]

\[ \neg a \quad \neg d \]

\[ \text{pref}(D) = \{ \{ a \mapsto t, b \mapsto f \} \} \]
Directional Splitting – Procedure

\[ \neg b \]

\[ \neg a \vee b \]

\[ \neg c \vee \neg e \]

\[ (c \vee d) \wedge \neg f \]

\[ \neg d \]

\[ \text{pref}(D) = \{ \{ a \mapsto t, b \mapsto f, \}
\]

\[ \{ a \mapsto f, b \mapsto t, \} \]
Directional Splitting – Procedure

\[ \neg b \]

\[ \neg a \]

\[ \neg c \lor \neg e \]

\[ (c \lor d) \land \neg f \]

\[ \neg d \]

\[ \neg \top \lor \bot \]

\[ \operatorname{pref}(D) = \{ \{ a \mapsto t, b \mapsto f \}, \{ a \mapsto f, b \mapsto t \} \} \]
Directional Splitting – Procedure

\[ \neg b \]

\[ \neg a \]

\[ \neg c \lor \neg e \]

\[ (c \lor d) \land \neg f \]

\[ \neg d \]

\[ \neg \top \lor \bot \]

\[ \text{pref}(D) = \{ \{ a \mapsto t, b \mapsto f, c \mapsto f \}, \{ a \mapsto f, b \mapsto t \} \} \]
Directional Splitting – Procedure

\[
\neg b \quad \neg \top \lor \bot \quad \neg \bot \lor \neg e \quad \neg d
\]

\[
\neg a \quad \neg \top \lor \bot \quad (\bot \lor d) \land \neg f
\]

\[
\text{pref}(D) = \{\{a \mapsto \text{t}, b \mapsto \text{f}, c \mapsto \text{f},} \\
\{a \mapsto \text{f}, b \mapsto \text{t},\}
\]
Directional Splitting – Procedure

\[ \neg b \]

\[ \neg T \lor \bot \]

\[ \neg \bot \lor \neg e \]

\[ \neg d \]

\[ (\bot \lor d) \land \neg f \]

\[ \text{pref}(D) = \{ \{ a \mapsto t, b \mapsto f, c \mapsto f, d \mapsto t, e \mapsto t, f \mapsto f \} , \{ a \mapsto f, b \mapsto t \} \} \]
Directional Splitting – Procedure

\[ \neg b \]
\[ \neg a \]
\[ \neg \bot \vee \top \]
\[ (c \lor d) \land \neg f \]
\[ \neg c \lor \neg e \]
\[ 
\begin{align*}
\text{pref}(D) &= \{a \mapsto t, b \mapsto f, c \mapsto f, d \mapsto t, e \mapsto t, f \mapsto f\}, \\
&\quad \{a \mapsto f, b \mapsto t, \}
\end{align*}
\]
Directional Splitting – Procedure

\[ \neg b \]

\[ \neg \bot \lor \top \]

\[ \neg c \lor \neg e \]

\[ (c \lor d) \land \neg f \]

\[ \neg d \]

\[ \text{pref}(D) = \begin{cases} 
\{ a \mapsto t, b \mapsto f, c \mapsto f, d \mapsto t, e \mapsto t, f \mapsto f \}, \\
\{ a \mapsto f, b \mapsto t, c \mapsto t, \} \end{cases} \]
Directional Splitting – Procedure

\[ \text{pref}(D) = \{\{a \mapsto t, b \mapsto f, c \mapsto f, d \mapsto t, e \mapsto t, f \mapsto f\}, \{a \mapsto f, b \mapsto t, c \mapsto t\} \} \]
\[ \text{pref}(D) = \big\{ \{a \mapsto t, b \mapsto f, c \mapsto f, d \mapsto t, e \mapsto t, f \mapsto f\}, \{a \mapsto f, b \mapsto t, c \mapsto t, d \mapsto u, e \mapsto u, f \mapsto u\} \big\} \]
Directional Splitting – Procedure

\[
\begin{align*}
\text{comp}(D) &= \{ \}
\end{align*}
\]
Directional Splitting – Procedure

\[ \top \quad \quad b \quad \quad \neg b \vee c \]

\[ \neg a \land b \]

\[
comp(D) = \{ \\
\}
\]
Directional Splitting – Procedure

\[ \text{comp}(D) = \{ \]

\[ \top \]

\[ \neg a \land b \quad \neg b \lor c \]

\[ D \]

\[ D \]

\[ D \]

\[ D \]
Directional Splitting – Procedure

\[ \text{comp}(D) = \{ \{ a \mapsto \text{t}, \ b \mapsto \text{t}, \ c \mapsto \text{f},\ d \mapsto \text{t} \} \} \]
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\[ \text{comp}(D) = \{ \{ a \mapsto t, b \mapsto t, c \mapsto f, d \mapsto f \} \} , \]
Directional Splitting – Procedure

\[ \text{comp}(D) = \begin{cases} \{ a \mapsto t, b \mapsto t, c \mapsto f, d \mapsto f \} , \\ \{ a \mapsto t, b \mapsto f, c \mapsto f \} , \\ \{ a \mapsto t, b \mapsto f, c \mapsto f \} \end{cases} \]
Directional Splitting – Procedure

\[ \text{comp}(D) = \left\{ \left\{ a \mapsto t, b \mapsto t, c \mapsto f, d \mapsto f \right\}, \right. \]
\[ \left. \left\{ a \mapsto t, b \mapsto f, c \mapsto f, d \mapsto f \right\}, \right\} \]
Directional Splitting – Procedure

\[
\begin{align*}
\text{comp}(D) &= \{ \{ a \mapsto t, b \mapsto t, c \mapsto f, d \mapsto f \}, \\
            &\quad \{ a \mapsto t, b \mapsto f, c \mapsto f, d \mapsto t \}, \\
            &\quad \{ a \mapsto t, b \mapsto u, c \mapsto f \} \},
\end{align*}
\]
Directional Splitting – Procedure

\[
\begin{align*}
\neg x_b \vee \bot & \quad \neg x_b \\
\comp(D) & = \left\{ \left\{ a \mapsto t, b \mapsto t, c \mapsto f, d \mapsto f \right\}, \right. \\
& \quad \left\{ a \mapsto t, b \mapsto f, c \mapsto f, d \mapsto t \right\}, \right. \\
& \quad \left\{ a \mapsto t, b \mapsto u, c \mapsto f \right\}, \\
& \quad \left\{ a \mapsto t, b \mapsto t, c \mapsto f, d \mapsto f \right\} \right\}.
\end{align*}
\]
Directional Splitting – Procedure

\[ \text{comp}(D) = \begin{cases} \{a \mapsto t, b \mapsto t, c \mapsto f, d \mapsto f\}, \\ \{a \mapsto t, b \mapsto f, c \mapsto f, d \mapsto t\}, \\ \{a \mapsto t, b \mapsto u, c \mapsto f, d \mapsto u, x_b \mapsto u\} \end{cases} \]
Definition

Given an ADF \( D \) we call a set \( S \subseteq A_D \) a general splitting of \( D \).
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Given an ADF $D$, let $L \subseteq L_D$ be a set of links in $D$ and $L^- = \{b \mid (b, a) \in L\}$. The $L$-elimination of $D$ is defined as

$$D^L = \{\langle a, \varphi_a[b/x_b : b \in L^-] \rangle \mid a \in A_D\} \cup$$

$$\{\langle x_b, x_b \rangle \mid b \in L^-\} \cup \{\langle \omega(D^L), \neg \left(\bigwedge_{b \in L^-} b \leftrightarrow x_b\right) \wedge \neg \omega(D^L) \rangle\}.$$
General Splitting

Definition

Given an ADF $D$, let $L \subseteq L_D$ be a set of links in $D$ and $L^- = \{b \mid (b, a) \in L\}$. The $L$-elimination of $D$ is defined as

$$D^L = \{\langle a, \varphi_a[b/x_b : b \in L^-] \rangle \mid a \in A_D\} \cup \{\langle x_b, x_b \rangle \mid b \in L^-\} \cup \{\langle \omega(D^L), \neg\left(\bigwedge_{b \in L^-} b \leftrightarrow x_b\right) \land \neg\omega(D^L) \rangle\}.$$ 

Proposition

Given an ADF $D$, for any $L \subseteq L_D$ it holds that

1. $v \in \text{mod}_2(D^L) \Rightarrow v|_{A_D} \in \text{mod}_2(D),$
2. $v \in \text{mod}_2(D) \Rightarrow \exists v' \in \text{val}_2(D^L) : v = v'|_{A_D}.$
Definition

Given an ADF $D$, let $S \subseteq A_D$ be a general splitting of $D$ and $B = \{ b \in (A_D \setminus S) \mid \exists a \in S : (b, a) \in L_D \}$. The primary slice of $D$ wrt. $S$ is defined as

$$D^S = \{ \langle a, \varphi_a[b/x_b : b \in B] \rangle \mid a \in S \} \cup \{ \langle x_b, x_b \rangle \mid b \in B \}.$$  

Moreover, if $\nu$ is an interpretation of $D^S$, the extended $\nu$-reduct of $D$ wrt. $S$ is defined as

$$D^{S,\nu} = D^\nu \cup \{ \langle \omega(D^{S,\nu}), \bigwedge_{b \in B, \nu(x_b)=t} b \wedge \bigwedge_{b \in B, \nu(x_b)=f} (\neg b) \rangle \}.$$
Theorem

Given an ADF $D$ and a general splitting $S \subseteq A_D$ thereof, let $B = \{ b \in (A_D \setminus S) \mid \exists a \in S : (b, a) \in L_D \}$. It holds that

1. $v_1 \in \text{adm}(D^S) \land v_2 \in \text{adm}(D^S, v_1) \land v_2(\omega(D^S, v_1)) = t \Rightarrow (v_1 \cup v_2)|_{A_D} \in \text{adm}(D)$

2. $v \in \text{adm}(D) \Rightarrow \exists v_1, v_2 : (v_1 \cup v_2)|_{A_D} = v \land v_1 \in \text{adm}(D^S) \land v_2 \in \text{adm}(D^S, v_1) \land v_2(\omega(D^S, v_1)) = t$
General Splitting – Procedure

Admissible interpretations:

\{ b \mapsto \rightarrow u, c \mapsto \rightarrow f, x \mapsto \rightarrow u, x \mapsto \rightarrow t, d \mapsto \rightarrow u, e \mapsto \rightarrow t, \omega \mapsto \rightarrow t \}.

\{ b \mapsto \rightarrow u, c \mapsto \rightarrow f, x \mapsto \rightarrow u, x \mapsto \rightarrow t, d \mapsto \rightarrow u, e \mapsto \rightarrow t, \omega \mapsto \rightarrow t \}.

General Splitting – Procedure

Admissible interpretations:
General Splitting – Procedure

Admissible interpretations:
\[\{ b \mapsto u, \, c \mapsto f, \, x_d \mapsto u, \, x_e \mapsto t \}\]
**General Splitting – Procedure**

Admissible interpretations:
\[
\{ b \mapsto \mathbf{u}, c \mapsto \mathbf{f}, x_d \mapsto \mathbf{u}, x_e \mapsto \mathbf{t}, \}
\]
General Splitting – Procedure

Admissible interpretations:
\[ \{ b \mapsto u, c \mapsto f, x_d \mapsto u, x_e \mapsto t, d \mapsto t, e \mapsto t, \omega \mapsto t \} , \]
General Splitting – Procedure

Admissible interpretations:

\{b \mapsto u, c \mapsto f, x_d \mapsto u, x_e \mapsto t, d \mapsto t, e \mapsto t, \omega \mapsto t\},
\{b \mapsto u, c \mapsto f, x_d \mapsto u, x_e \mapsto t, d \mapsto u, e \mapsto t, \omega \mapsto t\}
General Splitting
Conclusion

Summary

- Directional splitting for semantics from [Brewka et al., 2013].
  - Optimization of implementations of decision problems
- Preliminary results general splitting for models and admissible interpretation.
  - To be exploited in dynamic scenarios.
- Relations between semantics.

Future Work

- Integrate splitting techniques in implementations.
- Empirical evaluation.
- General splitting for the remaining semantics.
References I


References II

On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games.

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