DCR Execution Equivalence

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Abstract

We present an Isabelle formalization of the basics of DCR-graphs [1] before defining *Execution Equivalent* markings. We then prove that execution equivalent markings are perfectly interchangeable during process execution, yielding significant state-space reduction for execution-based model-checking of DCR graphs.

Contents

theory *DCRExecutionEquivalence*
  imports *Main*
begin

1 DCR processes

Although we use the term "process", the present theory formalises DCR graphs as defined in the original places and other papers.

type-synonym *event* = *nat*

The static structure. This encompasss the relations, the set of event *dom* of the process, and the labelling function *lab*. We do not explicitly enforce that relations and marking are confined to this set, except in definitions of enabledness and execution below.

record *rels* =

cond :: *event rel*
pend :: *event rel*
incl :: *event rel*
excl :: *event rel*

mist :: *event rel*

dom :: *event set*

The dynamic structure, called the marking

record *marking* =
Ex :: *event set*
In :: *event set*
Re :: *event set*

It will be convenient to have notation for the events required, excluded, etc. by a given event.

abbreviation *conds* :: *rels* ⇒ *event* ⇒ *event set*
where
$conds\ T\ e \equiv \{\ f\ .\ (f,e) \in cond\ T\ \}$

abbreviation *excls* :: *rels* ⇒ *event* ⇒ *event set*
where
$excls\ T\ e \equiv \{\ x\ .\ (e,x) \in excl\ T \wedge (e,x) \notin incl\ T\ \}$

abbreviation *incls* :: *rels* ⇒ *event* ⇒ *event set*
where
$incls\ T\ e \equiv \{\ x\ .\ (e,x) \in incl\ T\ \}$

abbreviation *resps* :: *rels* ⇒ *event* ⇒ *event set*
where
$resps\ T\ e \equiv \{\ f\ .\ (e,f) \in pend\ T\ \}$

abbreviation *mists* :: *rels* ⇒ *event* ⇒ *event set*
where
$mists\ T\ e \equiv \{\ f\ .\ (f,e) \in mist\ T\ \}$

Similarly, it is convenient to be able to identify directly the currently excluded events.

1.1 Execution semantics

definition *enabled* :: *rels* ⇒ *marking* ⇒ *event* ⇒ *bool*
where
$enabled\ T\ M\ e \equiv$
$e \in In\ M\ \wedge$
$(conds\ T\ e \cap In\ M) - Ex\ M = \{\} \wedge$
$(mists\ T\ e \cap In\ M) - (dom\ T - Re\ M) = \{\}$

definition *execute* :: *rels* ⇒ *marking* ⇒ *nat* ⇒ *marking*
where

execute T M e ≡ (|
  Ex = *Ex M* ∪ { *e* },
  In = (*In M* − *excls T e*) ∪ *incls T e*,
  Re = (*Re M* − { *e* }) ∪ *resps T e*
  |)

1.2 Execution Equivalence

definition *accepting* :: *marking* ⇒ *bool* **where**
  accepting M = (*Re M* ∩ *In M* = {})

fun *acceptingrun* :: *rels* ⇒ *marking* ⇒ *event list* ⇒ *bool* **where**
  acceptingrun T M [] = *accepting M*
| *acceptingrun T M* (*e*#*t*) = (*enabled T M e* ∧ *acceptingrun T* (*execute T M e*) *t*)

definition *all-conds* :: *rels* ⇒ *nat set* **where**
  all-conds T = { *fst rel* | *rel* . *rel* ∈ *cond T* }

definition *execution-equivalent* :: *rels* ⇒ *marking* ⇒ *marking* ⇒ *bool* **where**
  execution-equivalent T M1 M2 = (
    (*In M1* = *In M2*) ∧
    (*Re M1* = *Re M2*) ∧
    ((*Ex M1* ∩ *all-conds T*) = (*Ex M2* ∩ *all-conds T*))
)

lemma *cond-subset-eq-all-conds*: *conds T e* ⊆ *all-conds T*
  using *all-conds-def* **by** *auto*

lemma *ex-equiv-over-cond*: (*Ex M1* ∩ *all-conds T*) = (*Ex M2* ∩ *all-conds T*) ⟹
(*Ex M1* ∩ *conds T e*) = (*Ex M2* ∩ *conds T e*)
  using *conds-subset-eq-all-conds* **by** *blast*

lemma *enabled-ex-equiv*:
  assumes *execution-equivalent T M1 M2 enabled T M1 e*
  shows *enabled T M2 e*
proof −
  from *assms*(*1*) **have**
    (*Ex M1* ∩ *all-conds T*) = (*Ex M2* ∩ *all-conds T*)
    by (*simp add*: *execution-equivalent-def*)
  hence *ex-eq*:
    (*Ex M1* ∩ *conds T e*) = (*Ex M2* ∩ *conds T e*)
    using *ex-equiv-over-cond* **by** *metis*
  from *assms*(*1*) **have** *in-eq*:
    In M1 = *In M2*
    by (*simp add*: *execution-equivalent-def*)
  from *assms*(*2*) **have**
    (*conds T e* ∩ *In M1*) ⊆ *Ex M1*
    by(*simp-all add*: *enabled-def*)
  hence

(*conds T e* ∩ *In M1*) ∩ (*conds T e*) ⊆ *Ex M1* ∩ (*conds T e*)
    by *auto*
  hence
    (*conds T e* ∩ *In M1*) ⊆ *Ex M1* ∩ (*conds T e*)
    by *auto*
  hence
    (*conds T e* ∩ *In M2*) ⊆ *Ex M2* ∩ (*conds T e*)
    using *ex-eq in-eq* **by** *auto*
  hence
    (*conds T e* ∩ *In M2*) ⊆ *Ex M2*
    by *simp*
  then show *?thesis*
    using *enabled-def assms in-eq execution-equivalent-def* **by** *auto*
qed

lemma *execute-ex-equiv*:
  assumes *execution-equivalent T M1 M2 execute T M1 e = M3 execute T M2 e = M4*
  shows *execution-equivalent T M3 M4*
proof−
  from *assms* **have**
    In M3 = In M4
    using *execute-def execution-equivalent-def* **by** *fastforce*
  moreover from *assms* **have**
    Re M3 = Re M4
    using *execute-def execution-equivalent-def* **by** *force*
  ultimately show *?thesis* **using** *assms execute-def execution-equivalent-def*
    by *fastforce*
qed

lemma *accepting-ex-equiv*: *execution-equivalent T M1 M2* ⟹ *accepting M1* ⟹ *accepting M2*
  by (*simp add*: *accepting-def execution-equivalent-def*)

theorem *acceptingrun-ex-equiv*:
  assumes *acceptingrun T M1 seq execution-equivalent T M1 M2*
  shows *acceptingrun T M2 seq*
  using *assms*
proof(*induction seq arbitrary*: *M1 M2 rule*: *acceptingrun.induct*)
  case (*1 T M*)
  then show *?case*
    by (*simp add*: *accepting-ex-equiv*)
next
  case (*2 T M e t*)
  then show *?case* **proof**−
    from *2*(*2*) **obtain** *M1e* **where** *m1e*:
      M1e = execute T M1 e
      by *blast*
    hence *m1e-accept*:

acceptingrun T M1e t
using *2(2) acceptingrun.simps(2)* **by** *blast*
obtain *M2e* **where**
M2e = execute T M2 e
by *blast*
moreover from *this m1e* **have**
execution-equivalent T M1e M2e
using *2(3) execute-ex-equiv* **by** *blast*
moreover from *this* **have**
acceptingrun T M2e t
using *2(1) m1e-accept* **by** *blast*
ultimately show *?thesis* **using** *2(2) enabled-ex-equiv 2(3) acceptingrun.simps(2)* **by** *blast*
qed
qed

end

References

[1] C. O. Back, T. Slaats, T. T. Hildebrandt, and M. Marquard. Discover: accurate and efficient discovery of declarative process models. *International Journal on Software Tools for Technology Transfer*, pages 1–25, 2021.