

Dynamic Architectures

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Abstract

The architecture of a system describes the system's overall organization into components and connections between those components. With the emergence of mobile computing, dynamic architectures have become increasingly important. In such architectures, components may appear or disappear, and connections may change over time. In the following we mechanize a theory of dynamic architectures and verify the soundness of a corresponding calculus. Therefore, we first formalize the notion of configuration traces [5] as a model for dynamic architectures. Then, the behavior of single components is formalized in terms of behavior traces and an operator is introduced and studied to extract the behavior of a single component out of a given configuration trace. Then, behavior trace assertions are introduced as a temporal specification technique to specify behavior of components. Reasoning about component behavior in a dynamic context is formalized in terms of a calculus for dynamic architectures [3]. Finally, the soundness of the calculus is verified by introducing an alternative interpretation for behavior trace assertions over configuration traces and proving the rules of the calculus. Since projection may lead to finite as well as infinite behavior traces, they are formalized in terms of coinductive lists. Thus, our theory is based on Lochbihler's [1] formalization of coinductive lists. The theory may be applied to verify properties for dynamic architectures.

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1 A Theory of Dynamic Architectures

The following theory formalizes configuration traces [4, 5] as a model for dynamic architectures. Since configuration traces may be finite as well as infinite, the theory depends on Lochbihler's theory of co-inductive lists [1].

```
theory Configuration-Traces
imports Coinductive.Coinductive-List
begin
```

In the following we first provide some preliminary results for natural numbers, extended natural numbers, and lazy lists. Then, we introduce a locale `@textdynamic_architectures` which introduces basic definitions and corresponding properties for dynamic architectures.

1.1 Natural Numbers

We provide one additional property for natural numbers.

```
lemma boundedGreatest:
  assumes  $P (i::nat)$ 
  and  $\forall n' > n. \neg P n'$ 
  shows  $\exists i' \leq n. P i' \wedge (\forall n'. P n' \longrightarrow n' \leq i')$ 
<proof>
```

1.2 Extended Natural Numbers

We provide one simple property for the *strict* order over extended natural numbers.

```
lemma enat-min:
  assumes  $m \geq enat n'$ 
  and  $enat n < m - enat n'$ 
  shows  $enat n + enat n' < m$ 
<proof>
```

1.3 Lazy Lists

In the following we provide some additional notation and properties for lazy lists.

```
notation LNil ( $[]_l$ )
notation LCons (infixl  $\#_l$  60)
notation lappend (infixl  $@_l$  60)
```

```
lemma lnth-lappend[simp]:
  assumes lfinite xs
  and  $\neg lnull ys$ 
  shows  $lnth (xs @_l ys) (the-enat (llength xs)) = lhd ys$ 
<proof>
```

```
lemma lfilter-ltake:
  assumes  $\forall (n::nat) \leq llength xs. n \geq i \longrightarrow (\neg P (lnth xs n))$ 
  shows  $lfilter P xs = lfilter P (ltake i xs)$ 
<proof>
```

```
lemma lfilter-lfinite[simp]:
  assumes lfinite (lfilter P t)
  and  $\neg lfinite t$ 
```

shows $\exists n. \forall n' > n. \neg P (\text{lnth } t \ n')$
 <proof>

1.4 Specifying Dynamic Architectures

In the following we formalize dynamic architectures in terms of configuration traces, i.e., sequences of architecture configurations. Moreover, we introduce definitions for operations to support the specification of configuration traces.

typedecl *cnf*

type-synonym *trace* = *nat* \Rightarrow *cnf*

consts *arch*:: *trace set*

type-synonym *cta* = *trace* \Rightarrow *nat* \Rightarrow *bool*

1.4.1 Implication

definition *imp* :: *cta* \Rightarrow *cta* \Rightarrow *cta* (**infixl** \longrightarrow^c 10)

where $\gamma \longrightarrow^c \gamma' \equiv \lambda t \ n. \gamma \ t \ n \longrightarrow \gamma' \ t \ n$

declare *imp-def*[*simp*]

lemma *impI*[*intro!*]:

fixes *t n*

assumes $\gamma \ t \ n \Longrightarrow \gamma' \ t \ n$

shows $(\gamma \longrightarrow^c \gamma') \ t \ n$ <proof>

lemma *impE*[*elim!*]:

fixes *t n*

assumes $(\gamma \longrightarrow^c \gamma') \ t \ n$ **and** $\gamma \ t \ n$ **and** $\gamma' \ t \ n \Longrightarrow \gamma'' \ t \ n$

shows $\gamma'' \ t \ n$ <proof>

1.4.2 Disjunction

definition *disj* :: *cta* \Rightarrow *cta* \Rightarrow *cta* (**infixl** \vee^c 15)

where $\gamma \vee^c \gamma' \equiv \lambda t \ n. \gamma \ t \ n \vee \gamma' \ t \ n$

declare *disj-def*[*simp*]

lemma *disjI1*[*intro*]:

assumes $\gamma \ t \ n$

shows $(\gamma \vee^c \gamma') \ t \ n$ <proof>

lemma *disjI2*[*intro*]:

assumes $\gamma' \ t \ n$

shows $(\gamma \vee^c \gamma') \ t \ n$ <proof>

lemma *disjE*[*elim!*]:

assumes $(\gamma \vee^c \gamma') \ t \ n$

and $\gamma \ t \ n \Longrightarrow \gamma'' \ t \ n$

and $\gamma' \ t \ n \Longrightarrow \gamma'' \ t \ n$

shows $\gamma'' \ t \ n$ <proof>

1.4.3 Conjunction

definition *conj* :: *cta* \Rightarrow *cta* \Rightarrow *cta* (**infixl** \wedge^c 20)

where $\gamma \wedge^c \gamma' \equiv \lambda t n. \gamma t n \wedge \gamma' t n$

declare *conj-def*[*simp*]

lemma *conjI*[*intro!*]:

fixes n

assumes $\gamma t n$ **and** $\gamma' t n$

shows $(\gamma \wedge^c \gamma') t n$ *<proof>*

lemma *conjE*[*elim!*]:

fixes n

assumes $(\gamma \wedge^c \gamma') t n$ **and** $\gamma t n \implies \gamma' t n \implies \gamma'' t n$

shows $\gamma'' t n$ *<proof>*

1.4.4 Negation

definition *neg* :: $cta \Rightarrow cta$ (\neg^c - [19] 19)

where $\neg^c \gamma \equiv \lambda t n. \neg \gamma t n$

declare *neg-def*[*simp*]

lemma *negI*[*intro!*]:

assumes $\gamma t n \implies False$

shows $(\neg^c \gamma) t n$ *<proof>*

lemma *negE*[*elim!*]:

assumes $(\neg^c \gamma) t n$

and $\gamma t n$

shows $\gamma' t n$ *<proof>*

1.4.5 Quantifiers

definition *all* :: $(a \Rightarrow cta)$

$\Rightarrow cta$ (**binder** \forall_c 10)

where $all P \equiv \lambda t n. (\forall y. (P y t n))$

declare *all-def*[*simp*]

lemma *allI*[*intro!*]:

assumes $\bigwedge x. \gamma x t n$

shows $(\forall_c x. \gamma x) t n$ *<proof>*

lemma *allE*[*elim!*]:

fixes n

assumes $(\forall_c x. \gamma x) t n$ **and** $\gamma x t n \implies \gamma' t n$

shows $\gamma' t n$ *<proof>*

definition *ex* :: $(a \Rightarrow cta)$

$\Rightarrow cta$ (**binder** \exists_c 10)

where $ex P \equiv \lambda t n. (\exists y. (P y t n))$

declare *ex-def*[*simp*]

lemma *exI*[*intro!*]:

assumes $\gamma x t n$

shows $(\exists_c x. \gamma x) t n$ *<proof>*

lemma *exE[elim!]*:
assumes $(\exists_c x. \gamma x) t n$ **and** $\bigwedge x. \gamma x t n \implies \gamma' t n$
shows $\gamma' t n$ *<proof>*

1.4.6 Atomic Assertions

First we provide rules for basic behavior assertions.

definition *ca* :: $(cnf \Rightarrow bool) \Rightarrow cta$
where $ca \varphi \equiv \lambda t n. \varphi (t n)$

lemma *caI[intro]*:
fixes n
assumes $\varphi (t n)$
shows $(ca \varphi) t n$ *<proof>*

lemma *caE[elim]*:
fixes n
assumes $(ca \varphi) t n$
shows $\varphi (t n)$ *<proof>*

1.4.7 Next Operator

definition *next* :: $cta \Rightarrow cta$ ($\circ_c(-)$ 24)
where $\circ_c(\gamma) \equiv \lambda(t::(nat \Rightarrow cnf)) n. \gamma t (Suc n)$

1.4.8 Eventually Operator

definition *evt* :: $cta \Rightarrow cta$ ($\diamond_c(-)$ 23)
where $\diamond_c(\gamma) \equiv \lambda(t::(nat \Rightarrow cnf)) n. \exists n' \geq n. \gamma t n'$

1.4.9 Globally Operator

definition *glob* :: $cta \Rightarrow cta$ ($\square_c(-)$ 22)
where $\square_c(\gamma) \equiv \lambda(t::(nat \Rightarrow cnf)) n. \forall n' \geq n. \gamma t n'$

lemma *globI[intro!]*:
fixes n'
assumes $\forall n \geq n'. \gamma t n$
shows $(\square_c(\gamma)) t n'$ *<proof>*

lemma *globE[elim!]*:
fixes $n n'$
assumes $(\square_c(\gamma)) t n$ **and** $n' \geq n$
shows $\gamma t n'$ *<proof>*

1.4.10 Until Operator

definition *until* :: $cta \Rightarrow cta \Rightarrow cta$ (**infixl** \mathfrak{U}_c 21)
where $\gamma' \mathfrak{U}_c \gamma \equiv \lambda(t::(nat \Rightarrow cnf)) n. \exists n'' \geq n. \gamma t n'' \wedge (\forall n' \geq n. n' < n'' \longrightarrow \gamma' t n')$

lemma *untilI[intro]*:
fixes n
assumes $\exists n'' \geq n. \gamma t n'' \wedge (\forall n' \geq n. n' < n'' \longrightarrow \gamma' t n')$
shows $(\gamma' \mathfrak{U}_c \gamma) t n$ *<proof>*

lemma *untilE*[*elim*]:
fixes n
assumes $(\gamma' \mathfrak{U}_c \gamma) t n$
shows $\exists n'' \geq n. \gamma t n'' \wedge (\forall n' \geq n. n' < n'' \longrightarrow \gamma' t n')$ *<proof>*

1.4.11 Weak Until

definition *wuntil* :: $cta \Rightarrow cta \Rightarrow cta$ (**infixl** \mathfrak{W}_c 20)
where $\gamma' \mathfrak{W}_c \gamma \equiv \gamma' \mathfrak{U}_c \gamma \vee^c \square_c(\gamma')$

lemma *wUntilI*[*intro*]:
fixes n
assumes $(\exists n'' \geq n. \gamma t n'' \wedge (\forall n' \geq n. n' < n'' \longrightarrow \gamma' t n')) \vee (\forall n' \geq n. \gamma' t n')$
shows $(\gamma' \mathfrak{W}_c \gamma) t n$ *<proof>*

lemma *wUntilE*[*elim*]:
fixes $n n'$
assumes $(\gamma' \mathfrak{W}_c \gamma) t n$
shows $(\exists n'' \geq n. \gamma t n'' \wedge (\forall n' \geq n. n' < n'' \longrightarrow \gamma' t n')) \vee (\forall n' \geq n. \gamma' t n')$
<proof>

lemma *wUntil-Glob*:
assumes $(\gamma' \mathfrak{W}_c \gamma) t n$
and $(\square_c(\gamma' \longrightarrow^c \gamma'')) t n$
shows $(\gamma'' \mathfrak{W}_c \gamma) t n$
<proof>

1.5 Dynamic Components

To support the specification of patterns over dynamic architectures we provide a locale for dynamic components. It takes the following type parameters:

- *id*: a type for component identifiers
- *cmp*: a type for components
- *cnf*: a type for architecture configurations

locale *dynamic-component* =
fixes $tCMP :: 'id \Rightarrow cnf \Rightarrow 'cmp (\sigma_{-}(-) [0,110]60)$
and $active :: 'id \Rightarrow cnf \Rightarrow bool (\|\!-\!\| [0,110]60)$
begin

The locale requires two parameters:

- *tCMP* is an operator to obtain a component with a certain identifier from an architecture configuration.
- *active* is a predicate to assert whether a certain component is activated within an architecture configuration.

The locale provides some general properties about its parameters and introduces six important operators over configuration traces:

- An operator to extract the behavior of a certain component out of a given configuration trace.

- An operator to obtain the number of activations of a certain component within a given configuration trace.
- An operator to obtain the least point in time (before a certain point in time) from which on a certain component is not activated anymore.
- An operator to obtain the latest point in time where a certain component was activated.
- Two operators to map time-points between configuration traces and behavior traces.

Moreover, the locale provides several properties about the operators and their relationships.

lemma *nact-active*:

fixes $t::nat \Rightarrow cnf$
and $n::nat$
and n''
and id
assumes $\|id\|_t n$
and $n'' \geq n$
and $\neg (\exists n' \geq n. n' < n'' \wedge \|id\|_t n')$
shows $n = n''$
 $\langle proof \rangle$

lemma *nact-exists*:

fixes $t::nat \Rightarrow cnf$
assumes $\exists i \geq n. \|c\|_t i$
shows $\exists i \geq n. \|c\|_t i \wedge (\nexists k. n \leq k \wedge k < i \wedge \|c\|_t k)$
 $\langle proof \rangle$

lemma *lActive-least*:

assumes $\exists i \geq n. i < llength\ t \wedge \|c\|_{lnth\ t\ i}$
shows $\exists i \geq n. (i < llength\ t \wedge \|c\|_{lnth\ t\ i} \wedge (\nexists k. n \leq k \wedge k < i \wedge k < llength\ t \wedge \|c\|_{lnth\ t\ k}))$
 $\langle proof \rangle$

1.6 Projection

In the following we introduce an operator which extracts the behavior of a certain component out of a given configuration trace.

definition *proj*:: $'id \Rightarrow (cnf\ llist) \Rightarrow ('cmp\ llist) (\pi_-(\cdot) [0,110]60)$
where $proj\ c = lmap\ (\lambda cnf. (\sigma_c(cnf))) \circ (lfilter\ (active\ c))$

lemma *proj-lnil* [*simp,intro*]:

$\pi_c(\llbracket l \rrbracket) = \llbracket l \rrbracket$ $\langle proof \rangle$

lemma *proj-lnull* [*simp*]:

$\pi_c(t) = \llbracket l \rrbracket \longleftrightarrow (\forall k \in lset\ t. \neg \|c\|_k)$
 $\langle proof \rangle$

lemma *proj-LCons* [*simp*]:

$\pi_i(x \#_l xs) = (if\ \|i\|_x\ then\ (\sigma_i(x)) \#_l (\pi_i(xs))\ else\ \pi_i(xs))$
 $\langle proof \rangle$

lemma *proj-llength*[*simp*]:

$llength\ (\pi_c(t)) \leq llength\ t$
 $\langle proof \rangle$

lemma *proj-ltake*:

assumes $\forall (n'::nat) \leq \text{length } t. n' \geq n \longrightarrow (\neg \|c\|_{\text{nth } t \ n'})$
shows $\pi_c(t) = \pi_c(\text{ltake } n \ t)$ *<proof>*

lemma *proj-finite-bound*:

assumes *lfinite* $(\pi_c(\text{inf-llist } t))$
shows $\exists n. \forall n' > n. \neg \|c\|_t \ n'$
<proof>

1.6.1 Monotonicity and Continuity

lemma *proj-mcont*:

shows *mcont* *lSup* *lprefix* *lSup* *lprefix* $(\text{proj } c)$
<proof>

lemma *proj-mcont2mcont*:

assumes *mcont* *lub* *ord* *lSup* *lprefix* *f*
shows *mcont* *lub* *ord* *lSup* *lprefix* $(\lambda x. \pi_c(f \ x))$
<proof>

lemma *proj-mono-prefix[simp]*:

assumes *lprefix* $t \ t'$
shows *lprefix* $(\pi_c(t)) \ (\pi_c(t'))$
<proof>

1.6.2 Finiteness

lemma *proj-finite[simp]*:

assumes *lfinite* t
shows *lfinite* $(\pi_c(t))$
<proof>

lemma *proj-finite2*:

assumes $\forall (n'::nat) \leq \text{length } t. n' \geq n \longrightarrow (\neg \|c\|_{\text{nth } t \ n'})$
shows *lfinite* $(\pi_c(t))$ *<proof>*

lemma *proj-append-lfinite[simp]*:

fixes $t \ t'$
assumes *lfinite* t
shows $\pi_c(t \ @_l \ t') = (\pi_c(t)) \ @_l \ (\pi_c(t'))$ **(is ?lhs=?rhs)**
<proof>

lemma *proj-one*:

assumes $\exists i. i < \text{length } t \wedge \|c\|_{\text{nth } t \ i}$
shows $\text{length } (\pi_c(t)) \geq 1$
<proof>

1.6.3 Projection not Active

lemma *proj-not-active[simp]*:

assumes *enat* $n < \text{length } t$
and $\neg \|c\|_{\text{nth } t \ n}$
shows $\pi_c(\text{ltake } (Suc \ n) \ t) = \pi_c(\text{ltake } n \ t)$ **(is ?lhs = ?rhs)**
<proof>

lemma *proj-not-active-same*:

assumes $enat\ n \leq (n'::enat)$
and $\neg\ lfinite\ t \vee n'-1 < llength\ t$
and $\nexists k. k \geq n \wedge k < n' \wedge k < llength\ t \wedge \|c\|_{lnth\ t\ k}$
shows $\pi_c(ltake\ n'\ t) = \pi_c(ltake\ n\ t)$
 $\langle proof \rangle$

1.6.4 Projection Active

lemma *proj-active[simp]*:
assumes $enat\ i < llength\ t \ \|c\|_{lnth\ t\ i}$
shows $\pi_c(ltake\ (Suc\ i)\ t) = (\pi_c(ltake\ i\ t)) @_l ((\sigma_c(lnth\ t\ i)) \#_l [])$ (**is** $?lhs = ?rhs$)
 $\langle proof \rangle$

lemma *proj-active-append*:
assumes $a1: (n::nat) \leq i$
and $a2: enat\ i < (n'::enat)$
and $a3: \neg\ lfinite\ t \vee n'-1 < llength\ t$
and $a4: \|c\|_{lnth\ t\ i}$
and $\forall i'. (n \leq i' \wedge enat\ i' < n' \wedge i' < llength\ t \wedge \|c\|_{lnth\ t\ i'}) \longrightarrow (i' = i)$
shows $\pi_c(ltake\ n'\ t) = (\pi_c(ltake\ n\ t)) @_l ((\sigma_c(lnth\ t\ i)) \#_l [])$ (**is** $?lhs = ?rhs$)
 $\langle proof \rangle$

1.6.5 Same and not Same

lemma *proj-same-not-active*:
assumes $n \leq n'$
and $enat\ (n'-1) < llength\ t$
and $\pi_c(ltake\ n'\ t) = \pi_c(ltake\ n\ t)$
shows $\nexists k. k \geq n \wedge k < n' \wedge \|c\|_{lnth\ t\ k}$
 $\langle proof \rangle$

lemma *proj-not-same-active*:
assumes $enat\ n \leq (n'::enat)$
and $(\neg\ lfinite\ t) \vee n'-1 < llength\ t$
and $\neg(\pi_c(ltake\ n'\ t) = \pi_c(ltake\ n\ t))$
shows $\exists k. k \geq n \wedge k < n' \wedge enat\ k < llength\ t \wedge \|c\|_{lnth\ t\ k}$
 $\langle proof \rangle$

1.7 Activations

We also introduce an operator to obtain the number of activations of a certain component within a given configuration trace.

definition $nAct :: 'id \Rightarrow enat \Rightarrow (cnf\ llist) \Rightarrow enat\ (\langle - \#_- \rangle)$ **where**
 $\langle c \#_n t \rangle \equiv llength\ (\pi_c(ltake\ n\ t))$

lemma *nAct-0[simp]*:
 $\langle c \#_0 t \rangle = 0$ $\langle proof \rangle$

lemma *nAct-NIL[simp]*:
 $\langle c \#_n [] \rangle = 0$ $\langle proof \rangle$

lemma *nAct-Null*:
assumes $llength\ t \geq n$
and $\langle c \#_n t \rangle = 0$
shows $\forall i < n. \neg\ \|c\|_{lnth\ t\ i}$

<proof>

lemma *nAct-ge-one*[simp]:
 assumes $l\text{length } t \geq n$
 and $i < n$
 and $\|c\|_{l\text{nth } t } i$
 shows $\langle c \#_n t \rangle \geq \text{enat } 1$
<proof>

lemma *nAct-finite*[simp]:
 assumes $n \neq \infty$
 shows $\exists n'. \langle c \#_n t \rangle = \text{enat } n'$
<proof>

lemma *nAct-enat-the-nat*[simp]:
 assumes $n \neq \infty$
 shows $\text{enat } (\text{the-enat } (\langle c \#_n t \rangle)) = \langle c \#_n t \rangle$
<proof>

1.7.1 Monotonicity and Continuity

lemma *nAct-mcont*:
 shows $m\text{cont } l\text{Sup } l\text{prefix } \text{Sup } (\leq) (n\text{Act } c \ n)$
<proof>

lemma *nAct-mono*:
 assumes $n \leq n'$
 shows $\langle c \#_n t \rangle \leq \langle c \#_{n'} t \rangle$
<proof>

lemma *nAct-strict-mono-back*:
 assumes $\langle c \#_n t \rangle < \langle c \#_{n'} t \rangle$
 shows $n < n'$
<proof>

1.7.2 Not Active

lemma *nAct-not-active*[simp]:
 fixes $n::\text{nat}$
 and $n':\text{nat}$
 and $t::(\text{cnf } l\text{list})$
 and $c::'\text{id}$
 assumes $\text{enat } i < l\text{length } t$
 and $\neg \|c\|_{l\text{nth } t } i$
 shows $\langle c \#_{\text{Suc } i} t \rangle = \langle c \#_i t \rangle$
<proof>

lemma *nAct-not-active-same*:
 assumes $\text{enat } n \leq (n':\text{enat})$
 and $n'-1 < l\text{length } t$
 and $\nexists k. \text{enat } k \geq n \wedge k < n' \wedge \|c\|_{l\text{nth } t } k$
 shows $\langle c \#_{n'} t \rangle = \langle c \#_n t \rangle$
<proof>

1.7.3 Active

lemma *nAct-active[simp]*:

fixes $n::nat$
and $n':nat$
and $t::(cnf\ llist)$
and $c::'id$
assumes $enat\ i < llength\ t$
and $\|c\|_{lnth\ t\ i}$
shows $\langle c \#_{Suc\ i}\ t \rangle = eSuc\ (\langle c \#_i\ t \rangle)$
 $\langle proof \rangle$

lemma *nAct-active-suc*:

fixes $n::nat$
and $n':enat$
and $t::(cnf\ llist)$
and $c::'id$
assumes $\neg\ lfinite\ t \vee n'-1 < llength\ t$
and $n \leq i$
and $enat\ i < n'$
and $\|c\|_{lnth\ t\ i}$
and $\forall i'. (n \leq i' \wedge enat\ i' < n' \wedge i' < llength\ t \wedge \|c\|_{lnth\ t\ i'}) \longrightarrow (i' = i)$
shows $\langle c \#_{n'}\ t \rangle = eSuc\ (\langle c \#_n\ t \rangle)$
 $\langle proof \rangle$

lemma *nAct-less*:

assumes $enat\ k < llength\ t$
and $n \leq k$
and $k < (n':enat)$
and $\|c\|_{lnth\ t\ k}$
shows $\langle c \#_n\ t \rangle < \langle c \#_{n'}\ t \rangle$
 $\langle proof \rangle$

lemma *nAct-less-active*:

assumes $n' - 1 < llength\ t$
and $\langle c \#_{enat\ n}\ t \rangle < \langle c \#_{n'}\ t \rangle$
shows $\exists i \geq n. i < n' \wedge \|c\|_{lnth\ t\ i}$
 $\langle proof \rangle$

1.7.4 Same and Not Same

lemma *nAct-same-not-active*:

assumes $\langle c \#_{n'}\ inf\ llist\ t \rangle = \langle c \#_n\ inf\ llist\ t \rangle$
shows $\forall k \geq n. k < n' \longrightarrow \neg \|c\|_{t\ k}$
 $\langle proof \rangle$

lemma *nAct-not-same-active*:

assumes $\langle c \#_{enat\ n}\ t \rangle < \langle c \#_{n'}\ t \rangle$
and $\neg\ lfinite\ t \vee n' - 1 < llength\ t$
shows $\exists (i::nat) \geq n. enat\ i < n' \wedge i < llength\ t \wedge \|c\|_{lnth\ t\ i}$
 $\langle proof \rangle$

lemma *nAct-less-length-active*:

assumes $x < llength\ (\pi_c(t))$
and $enat\ x = \langle c \#_{enat\ n'}\ t \rangle$
shows $\exists (i::nat) \geq n'. i < llength\ t \wedge \|c\|_{lnth\ t\ i}$

<proof>

lemma *nAct-exists*:

assumes $x < \text{length } (\pi_c(t))$

shows $\exists (n'::\text{nat}). \text{enat } x = \langle c \#_{n'} t \rangle$

<proof>

1.8 Projection and Activation

In the following we provide some properties about the relationship between the projection and activations operator.

lemma *nAct-le-proj*:

$\langle c \#_n t \rangle \leq \text{length } (\pi_c(t))$

<proof>

lemma *proj-nAct*:

assumes $(\text{enat } n < \text{length } t)$

shows $\pi_c(\text{ltake } n \ t) = \text{ltake } (\langle c \#_n t \rangle) (\pi_c(t))$ (**is** ?lhs = ?rhs)

<proof>

lemma *proj-active-nth*:

assumes $\text{enat } (\text{Suc } i) < \text{length } t \ \parallel c \parallel_{\text{lnth } t \ i}$

shows $\text{lnth } (\pi_c(t)) (\text{the-enat } (\langle c \#_i t \rangle)) = \sigma_c(\text{lnth } t \ i)$

<proof>

lemma *nAct-eq-proj*:

assumes $\neg(\exists i \geq n. \parallel c \parallel_{\text{lnth } t \ i})$

shows $\langle c \#_n t \rangle = \text{length } (\pi_c(t))$ (**is** ?lhs = ?rhs)

<proof>

lemma *nAct-llength-proj*:

assumes $\exists i \geq n. \parallel c \parallel_{t \ i}$

shows $\text{length } (\pi_c(\text{inf-llist } t)) \geq \text{eSuc } (\langle c \#_n \text{inf-llist } t \rangle)$

<proof>

1.9 Least not Active

In the following, we introduce an operator to obtain the least point in time before a certain point in time where a component was deactivated.

definition *lNAct* :: $'id \Rightarrow (\text{nat} \Rightarrow \text{cnf}) \Rightarrow \text{nat} \Rightarrow \text{nat} (\langle - \Leftarrow - \rangle)$

where $\langle c \Leftarrow t \rangle_n \equiv (\text{LEAST } n'. n = n' \vee (n' < n \wedge (\nexists k. k \geq n' \wedge k < n \wedge \parallel c \parallel_{t \ k})))$

lemma *lNact0[simp]*:

$\langle c \Leftarrow t \rangle_0 = 0$

<proof>

lemma *lNact-least*:

assumes $n = n' \vee n' < n \wedge (\nexists k. k \geq n' \wedge k < n \wedge \parallel c \parallel_{t \ k})$

shows $\langle c \Leftarrow t \rangle_n \leq n'$

<proof>

lemma *lNact-ex*: $\langle c \Leftarrow t \rangle_n = n \vee \langle c \Leftarrow t \rangle_n < n \wedge (\nexists k. k \geq \langle c \Leftarrow t \rangle_n \wedge k < n \wedge \parallel c \parallel_{t \ k})$

<proof>

lemma *lNact-notActive*:

fixes $c\ t\ n\ k$
assumes $k \geq \langle c \Leftarrow t \rangle_n$
and $k < n$
shows $\neg \|c\|_t\ k$
 $\langle proof \rangle$

lemma *lNactGe*:

fixes $c\ t\ n\ n'$
assumes $n' \geq \langle c \Leftarrow t \rangle_n$
and $\|c\|_t\ n'$
shows $n' \geq n$
 $\langle proof \rangle$

lemma *lNactLe[simp]*:

fixes $n\ n'$
shows $\langle c \Leftarrow t \rangle_n \leq n$
 $\langle proof \rangle$

lemma *lNactLe-nact*:

fixes $n\ n'$
assumes $n' = n \vee (n' < n \wedge (\nexists k. k \geq n' \wedge k < n \wedge \|c\|_t\ k))$
shows $\langle c \Leftarrow t \rangle_n \leq n'$
 $\langle proof \rangle$

lemma *lNact-active*:

fixes $cid\ t\ n$
assumes $\forall k < n. \|cid\|_t\ k$
shows $\langle cid \Leftarrow t \rangle_n = n$
 $\langle proof \rangle$

lemma *nAct-mono-back*:

fixes $c\ t$ **and** n **and** n'
assumes $\langle c \#_{n'} \text{ inf-llist } t \rangle \geq \langle c \#_n \text{ inf-llist } t \rangle$
shows $n' \geq \langle c \Leftarrow t \rangle_n$
 $\langle proof \rangle$

lemma *nAct-mono-lNact*:

assumes $\langle c \Leftarrow t \rangle_n \leq n'$
shows $\langle c \#_n \text{ inf-llist } t \rangle \leq \langle c \#_{n'} \text{ inf-llist } t \rangle$
 $\langle proof \rangle$

1.10 Next Active

In the following, we introduce an operator to obtain the next point in time when a component is activated.

definition *nextAct* :: $'id \Rightarrow (nat \Rightarrow cnf) \Rightarrow nat \Rightarrow nat \ (\langle - \rightarrow - \rangle)$

where $\langle c \rightarrow t \rangle_n \equiv (THE\ n'.\ n' \geq n \wedge \|c\|_t\ n' \wedge (\nexists k. k \geq n \wedge k < n' \wedge \|c\|_t\ k))$

lemma *nextActI*:

fixes $n::nat$
and $t::nat \Rightarrow cnf$
and $c::'id$
assumes $\exists i \geq n. \|c\|_t\ i$
shows $\langle c \rightarrow t \rangle_n \geq n \wedge \|c\|_t\ \langle c \rightarrow t \rangle_n \wedge (\nexists k. k \geq n \wedge k < \langle c \rightarrow t \rangle_n \wedge \|c\|_t\ k)$

$\langle proof \rangle$

lemma *nxtActLe*:

fixes $n\ n'$

assumes $\exists i \geq n. \|c\|_t\ i$

shows $n \leq \langle c \rightarrow t \rangle_n$

$\langle proof \rangle$

lemma *nxtAct-eq*:

assumes $n' \geq n$

and $\|c\|_t\ n'$

and $\forall n'' \geq n. n'' < n' \longrightarrow \neg \|c\|_t\ n''$

shows $n' = \langle c \rightarrow t \rangle_n$

$\langle proof \rangle$

lemma *nxtAct-active*:

fixes $i::nat$

and $t::nat \Rightarrow cnf$

and $c::'id$

assumes $\|c\|_t\ i$

shows $\langle c \rightarrow t \rangle_i = i$ $\langle proof \rangle$

lemma *nxtActive-no-active*:

assumes $\exists! i. i \geq n \wedge \|c\|_t\ i$

shows $\neg (\exists i' \geq Suc\ \langle c \rightarrow t \rangle_n. \|c\|_t\ i')$

$\langle proof \rangle$

lemma *nxt-geq-lNact[simp]*:

assumes $\exists i \geq n. \|c\|_t\ i$

shows $\langle c \rightarrow t \rangle_n \geq \langle c \leftarrow t \rangle_n$

$\langle proof \rangle$

lemma *active-geq-nxtAct*:

assumes $\|c\|_t\ i$

and $the-enat\ (\langle c \#_i\ inf-llist\ t \rangle) \geq the-enat\ (\langle c \#_n\ inf-llist\ t \rangle)$

shows $i \geq \langle c \rightarrow t \rangle_n$

$\langle proof \rangle$

lemma *nAct-same*:

assumes $\langle c \leftarrow t \rangle_n \leq n'$ **and** $n' \leq \langle c \rightarrow t \rangle_n$

shows $the-enat\ (\langle c \#_{enat\ n'}\ inf-llist\ t \rangle) = the-enat\ (\langle c \#_{enat\ n}\ inf-llist\ t \rangle)$

$\langle proof \rangle$

lemma *nAct-mono-nxtAct*:

assumes $\exists i \geq n. \|c\|_t\ i$

and $\langle c \rightarrow t \rangle_n \leq n'$

shows $\langle c \#_n\ inf-llist\ t \rangle \leq \langle c \#_{n'}\ inf-llist\ t \rangle$

$\langle proof \rangle$

1.11 Latest Activation

In the following, we introduce an operator to obtain the latest point in time when a component is activated.

abbreviation *latestAct-cond*:: $'id \Rightarrow trace \Rightarrow nat \Rightarrow nat \Rightarrow bool$

where $latestAct-cond\ c\ t\ n\ n' \equiv n' < n \wedge \|c\|_t\ n'$

definition *latestAct*:: 'id \Rightarrow trace \Rightarrow nat \Rightarrow nat ($\langle - \leftarrow - \rangle$ -)
where *latestAct* c t n = (GREATEST n'. *latestAct-cond* c t n n')

lemma *latestActEx*:

assumes $\exists n' < n. \|nid\|_t n'$

shows $\exists n'. \text{latestAct-cond } nid \ t \ n \ n' \wedge (\forall n''. \text{latestAct-cond } nid \ t \ n \ n'' \longrightarrow n'' \leq n')$

<proof>

lemma *latestAct-prop*:

assumes $\exists n' < n. \|nid\|_t n'$

shows $\|nid\|_t (\text{latestAct } nid \ t \ n)$ **and** *latestAct* nid t n < n

<proof>

lemma *latestAct-less*:

assumes *latestAct-cond* nid t n n'

shows $n' \leq \langle nid \leftarrow t \rangle_n$

<proof>

lemma *latestActNxt*:

assumes $\exists n' < n. \|nid\|_t n'$

shows $\langle nid \rightarrow t \rangle_{\langle nid \leftarrow t \rangle_n} = \langle nid \leftarrow t \rangle_n$

<proof>

lemma *latestActNxtAct*:

assumes $\exists n' \geq n. \|tid\|_t n'$

and $\exists n' < n. \|tid\|_t n'$

shows $\langle tid \rightarrow t \rangle_n > \langle tid \leftarrow t \rangle_n$

<proof>

lemma *latestActless*:

assumes $\exists n' \geq n_s. n' < n \wedge \|nid\|_t n'$

shows $\langle nid \leftarrow t \rangle_{n \geq n_s}$

<proof>

lemma *latestActEq*:

fixes *nid*::'id

assumes $\|nid\|_t n'$ **and** $\neg(\exists n'' > n'. n'' < n \wedge \|nid\|_t n')$ **and** $n' < n$

shows $\langle nid \leftarrow t \rangle_n = n'$

<proof>

1.12 Last Activation

In the following we introduce an operator to obtain the latest point in time where a certain component was activated within a certain configuration trace.

definition *lActive* :: 'id \Rightarrow (nat \Rightarrow cnf) \Rightarrow nat ($\langle - \wedge - \rangle$)

where $\langle c \wedge t \rangle \equiv (\text{GREATEST } i. \|c\|_t i)$

lemma *lActive-active*:

assumes $\|c\|_t i$

and $\forall n' > n. \neg(\|c\|_t n')$

shows $\|c\|_t (\langle c \wedge t \rangle)$

<proof>

lemma *lActive-less*:

assumes $\|c\|_t i$
and $\forall n' > n. \neg (\|c\|_t n')$
shows $\langle c \wedge t \rangle \leq n$

<proof>

lemma *lActive-greatest*:

assumes $\|c\|_t i$
and $\forall n' > n. \neg (\|c\|_t n')$
shows $i \leq \langle c \wedge t \rangle$

<proof>

lemma *lActive-greater-active*:

assumes $n > \langle c \wedge t \rangle$
and $\forall n'' > n'. \neg \|c\|_t n''$
shows $\neg \|c\|_t n$

<proof>

lemma *lActive-greater-active-all*:

assumes $\forall n'' > n'. \neg \|c\|_t n''$
shows $\neg (\exists n > \langle c \wedge t \rangle. \|c\|_t n)$

<proof>

lemma *lActive-equality*:

assumes $\|c\|_t i$
and $(\bigwedge x. \|c\|_t x \implies x \leq i)$
shows $\langle c \wedge t \rangle = i$ *<proof>*

lemma *nextActive-lactive*:

assumes $\exists i \geq n. \|c\|_t i$
and $\neg (\exists i > \langle c \rightarrow t \rangle_n. \|c\|_t i)$
shows $\langle c \rightarrow t \rangle_n = \langle c \wedge t \rangle$

<proof>

1.13 Mapping Time Points

In the following we introduce two operators to map time-points between configuration traces and behavior traces.

1.13.1 Configuration Trace to Behavior Trace

First we provide an operator which maps a point in time of a configuration trace to the corresponding point in time of a behavior trace.

definition *cnf2bhv* :: $'id \Rightarrow (nat \Rightarrow cnf) \Rightarrow nat \Rightarrow nat \rightarrow nat \rightarrow (-\downarrow(-) [150,150,150] 110)$
where $c\downarrow_t(n) \equiv the-enat(llength (\pi_c(inf-llist t))) - 1 + (n - \langle c \wedge t \rangle)$

lemma *cnf2bhv-mono*:

assumes $n' \geq n$
shows $c\downarrow_t(n') \geq c\downarrow_t(n)$
<proof>

lemma *cnf2bhv-mono-strict*:

assumes $n \geq \langle c \wedge t \rangle$ **and** $n' > n$
shows $c\downarrow_t(n') > c\downarrow_t(n)$

⟨proof⟩

Note that the functions are nat, that means that also in the case the difference is negative they will return a 0!

lemma *cnf2bhv-ge-llength[simp]*:
assumes $n \geq \langle c \wedge t \rangle$
shows $c \downarrow_t(n) \geq \text{the-enat}(\text{llength}(\pi_c(\text{inf-list } t))) - 1$
 ⟨proof⟩

lemma *cnf2bhv-greater-llength[simp]*:
assumes $n > \langle c \wedge t \rangle$
shows $c \downarrow_t(n) > \text{the-enat}(\text{llength}(\pi_c(\text{inf-list } t))) - 1$
 ⟨proof⟩

lemma *cnf2bhv-suc[simp]*:
assumes $n \geq \langle c \wedge t \rangle$
shows $c \downarrow_t(\text{Suc } n) = \text{Suc}(c \downarrow_t(n))$
 ⟨proof⟩

lemma *cnf2bhv-lActive[simp]*:
shows $c \downarrow_t(\langle c \wedge t \rangle) = \text{the-enat}(\text{llength}(\pi_c(\text{inf-list } t))) - 1$
 ⟨proof⟩

lemma *cnf2bhv-lnth-lappend*:
assumes $\text{act}: \exists i. \|c\|_t i$
and $n \text{Act}: \nexists i. i \geq n \wedge \|c\|_t i$
shows $\text{lnth}((\pi_c(\text{inf-list } t)) @_l (\text{inf-list } t'))(c \downarrow_t(n)) = \text{lnth}(\text{inf-list } t')(n - \langle c \wedge t \rangle - 1)$
(is ?lhs = ?rhs)
 ⟨proof⟩

lemma *nAct-cnf2proj-Suc-dist*:
assumes $\exists i \geq n. \|c\|_t i$
and $\neg(\exists i > \langle c \rightarrow t \rangle_n. \|c\|_t i)$
shows $\text{Suc}(\text{the-enat}(\langle c \#_{\text{enat}} n \text{inf-list } t \rangle)) = c \downarrow_t(\text{Suc}(\langle c \rightarrow t \rangle_n))$
 ⟨proof⟩

1.13.2 Behavior Trace to Configuration Trace

Next we define an operator to map a point in time of a behavior trace back to a corresponding point in time for a configuration trace.

definition *bhv2cnf* :: $'id \Rightarrow (\text{nat} \Rightarrow \text{cnf}) \Rightarrow \text{nat} \Rightarrow \text{nat} \Rightarrow \text{nat} \Rightarrow \text{nat} \Rightarrow [150,150,150] \Rightarrow 110)$
where $c \uparrow_t(n) \equiv \langle c \wedge t \rangle + (n - (\text{the-enat}(\text{llength}(\pi_c(\text{inf-list } t))) - 1))$

lemma *bhv2cnf-mono*:
assumes $n' \geq n$
shows $c \uparrow_t(n') \geq c \uparrow_t(n)$
 ⟨proof⟩

lemma *bhv2cnf-mono-strict*:
assumes $n' > n$
and $n \geq \text{the-enat}(\text{llength}(\pi_c(\text{inf-list } t))) - 1$
shows $c \uparrow_t(n') > c \uparrow_t(n)$
 ⟨proof⟩

Note that the functions are nat, that means that also in the case the difference is negative they

will return a 0!

lemma *bhv2cnf-ge-lActive*[simp]:

shows $c \uparrow_t(n) \geq \langle c \wedge t \rangle$
 $\langle \text{proof} \rangle$

lemma *bhv2cnf-greater-lActive*[simp]:

assumes $n > \text{the-enat}(\text{llength}(\pi_c(\text{inf-list } t))) - 1$
shows $c \uparrow_t(n) > \langle c \wedge t \rangle$
 $\langle \text{proof} \rangle$

lemma *bhv2cnf-lActive*[simp]:

assumes $\exists i. \|c\|_t i$
and $\text{lfinite}(\pi_c(\text{inf-list } t))$
shows $c \uparrow_t(\text{the-enat}(\text{llength}(\pi_c(\text{inf-list } t)))) = \text{Suc}(\langle c \wedge t \rangle)$
 $\langle \text{proof} \rangle$

1.13.3 Relating the Mappings

In the following we provide some properties about the relationship between the two mapping operators.

lemma *bhv2cnf-cnf2bhv*:

assumes $n \geq \langle c \wedge t \rangle$
shows $c \uparrow_t(c \downarrow_t(n)) = n$ (**is** $?lhs = ?rhs$)
 $\langle \text{proof} \rangle$

lemma *cnf2bhv-bhv2cnf*:

assumes $n \geq \text{the-enat}(\text{llength}(\pi_c(\text{inf-list } t))) - 1$
shows $c \downarrow_t(c \uparrow_t(n)) = n$ (**is** $?lhs = ?rhs$)
 $\langle \text{proof} \rangle$

lemma *p2c-mono-c2p*:

assumes $n \geq \langle c \wedge t \rangle$
and $n' \geq c \downarrow_t(n)$
shows $c \uparrow_t(n') \geq n$
 $\langle \text{proof} \rangle$

lemma *p2c-mono-c2p-strict*:

assumes $n \geq \langle c \wedge t \rangle$
and $n < c \uparrow_t(n')$
shows $c \downarrow_t(n) < n'$
 $\langle \text{proof} \rangle$

lemma *c2p-mono-p2c*:

assumes $n \geq \text{the-enat}(\text{llength}(\pi_c(\text{inf-list } t))) - 1$
and $n' \geq c \uparrow_t(n)$
shows $c \downarrow_t(n') \geq n$
 $\langle \text{proof} \rangle$

lemma *c2p-mono-p2c-strict*:

assumes $n \geq \text{the-enat}(\text{llength}(\pi_c(\text{inf-list } t))) - 1$
and $n < c \downarrow_t(n')$
shows $c \uparrow_t(n) < n'$
 $\langle \text{proof} \rangle$

end

end

2 A Calculus for Dynamic Architectures

The following theory formalizes our calculus for dynamic architectures [2, 3] and verifies its soundness. The calculus allows to reason about temporal-logic specifications of component behavior in a dynamic setting. The theory is based on our theory of configuration traces and introduces the notion of behavior trace assertion to specify component behavior in a dynamic setting.

theory *Dynamic-Architecture-Calculus*
imports *Configuration-Traces*
begin

2.1 Extended Natural Numbers

We first provide one additional property for extended natural numbers.

lemma *the-enat-mono[simp]*:
assumes $m \neq \infty$
and $n \leq m$
shows $\text{the-enat } n \leq \text{the-enat } m$
 $\langle \text{proof} \rangle$

2.2 Lazy Lists

Finally, we provide an additional property for lazy lists.

lemma *llength-geq-enat-lfiniteD*: $\text{llength } xs \leq \text{enat } n \implies \text{lfinite } xs$
 $\langle \text{proof} \rangle$

context *dynamic-component*
begin

2.3 Dynamic Evaluation of Temporal Operators

In the following we introduce a function to evaluate a behavior trace assertion over a given configuration trace.

type-synonym $'c \text{ bta} = (\text{nat} \Rightarrow 'c) \Rightarrow \text{nat} \Rightarrow \text{bool}$

definition *eval*:: $'id \Rightarrow (\text{nat} \Rightarrow \text{cnf}) \Rightarrow (\text{nat} \Rightarrow 'cmp) \Rightarrow \text{nat} \Rightarrow 'cmp \text{ bta} \Rightarrow \text{bool}$

where $\text{eval } cid \ t \ t' \ n \ \gamma \equiv$

$$\begin{aligned} & (\exists i \geq n. \|cid\|_t \ i) \wedge \gamma (\text{lnth } ((\pi_{cid}(\text{inf-llist } t)) @_l (\text{inf-llist } t'))) (\text{the-enat}(\langle cid \#_n \text{inf-llist } t \rangle)) \vee \\ & (\exists i. \|cid\|_t \ i) \wedge (\nexists i'. i' \geq n \wedge \|cid\|_t \ i') \wedge \gamma (\text{lnth } ((\pi_{cid}(\text{inf-llist } t)) @_l (\text{inf-llist } t'))) (cid \downarrow_t (n)) \vee \\ & (\nexists i. \|cid\|_t \ i) \wedge \gamma (\text{lnth } ((\pi_{cid}(\text{inf-llist } t)) @_l (\text{inf-llist } t'))) \ n \end{aligned}$$

eval takes a component identifier *cid*, a configuration trace *t*, a behavior trace *t'*, and point in time *n* and evaluates behavior trace assertion γ as follows:

- If component *cid* is again activated in the future, γ is evaluated at the next point in time where *cid* is active in *t*.

- If component cid is not again activated in the future but it is activated at least once in t , then γ is evaluated at the point in time given by $cid \downarrow_t n$.
- If component cid is never active in t , then γ is evaluated at time point n .

The following proposition evaluates definition $eval$ by showing that a behavior trace assertion γ holds over configuration trace t and continuation t' whenever it holds for the concatenation of the corresponding projection with t' .

proposition $eval\text{-}corr$:

$eval\ cid\ t\ t'\ 0\ \gamma \longleftrightarrow \gamma\ (lnth\ ((\pi_{cid}(inf\text{-}llist\ t))\ @_l\ (inf\text{-}llist\ t')))\ 0$
 $\langle proof \rangle$

2.3.1 Simplification Rules

lemma $validCI\text{-}act[simp]$:

assumes $\exists i \geq n. \|cid\|_t\ i$
and $\gamma\ (lnth\ ((\pi_{cid}(inf\text{-}llist\ t))\ @_l\ (inf\text{-}llist\ t')))\ (the\text{-}enat(\langle cid\ \#_n\ inf\text{-}llist\ t \rangle))$
shows $eval\ cid\ t\ t'\ n\ \gamma$
 $\langle proof \rangle$

lemma $validCI\text{-}cont[simp]$:

assumes $\exists i. \|cid\|_t\ i$
and $\nexists i'. i' \geq n \wedge \|cid\|_{t\ i'}$
and $\gamma\ (lnth\ ((\pi_{cid}(inf\text{-}llist\ t))\ @_l\ (inf\text{-}llist\ t')))\ (cid \downarrow_t(n))$
shows $eval\ cid\ t\ t'\ n\ \gamma$
 $\langle proof \rangle$

lemma $validCI\text{-}not\text{-}act[simp]$:

assumes $\nexists i. \|cid\|_t\ i$
and $\gamma\ (lnth\ ((\pi_{cid}(inf\text{-}llist\ t))\ @_l\ (inf\text{-}llist\ t')))\ n$
shows $eval\ cid\ t\ t'\ n\ \gamma$
 $\langle proof \rangle$

lemma $validCE\text{-}act[simp]$:

assumes $\exists i \geq n. \|cid\|_t\ i$
and $eval\ cid\ t\ t'\ n\ \gamma$
shows $\gamma\ (lnth\ ((\pi_{cid}(inf\text{-}llist\ t))\ @_l\ (inf\text{-}llist\ t')))\ (the\text{-}enat(\langle cid\ \#_n\ inf\text{-}llist\ t \rangle))$
 $\langle proof \rangle$

lemma $validCE\text{-}cont[simp]$:

assumes $\exists i. \|cid\|_t\ i$
and $\nexists i'. i' \geq n \wedge \|cid\|_{t\ i'}$
and $eval\ cid\ t\ t'\ n\ \gamma$
shows $\gamma\ (lnth\ ((\pi_{cid}(inf\text{-}llist\ t))\ @_l\ (inf\text{-}llist\ t')))\ (cid \downarrow_t(n))$
 $\langle proof \rangle$

lemma $validCE\text{-}not\text{-}act[simp]$:

assumes $\nexists i. \|cid\|_t\ i$
and $eval\ cid\ t\ t'\ n\ \gamma$
shows $\gamma\ (lnth\ ((\pi_{cid}(inf\text{-}llist\ t))\ @_l\ (inf\text{-}llist\ t')))\ n$
 $\langle proof \rangle$

2.3.2 No Activations

proposition $validity1$:

assumes $n \leq n'$
and $\exists i \geq n'. \|c\|_t i$
and $\forall k \geq n. k < n' \longrightarrow \neg \|c\|_t k$
shows $eval\ c\ t\ t'\ n\ \gamma \Longrightarrow eval\ c\ t\ t'\ n'\ \gamma$
 <proof>

proposition *validity2*:

assumes $n \leq n'$
and $\exists i \geq n'. \|c\|_t i$
and $\forall k \geq n. k < n' \longrightarrow \neg \|c\|_t k$
shows $eval\ c\ t\ t'\ n'\ \gamma \Longrightarrow eval\ c\ t\ t'\ n\ \gamma$
 <proof>

2.4 Specification Operators

In the following we introduce some basic operators for behavior trace assertions.

2.4.1 Predicates

Every predicate can be transformed to a behavior trace assertion.

definition $pred :: bool \Rightarrow ('cmp\ bta)$
where $pred\ P \equiv \lambda\ t\ n. P$

lemma $predI[intro]$:

fixes $cid\ t\ t'\ n\ P$
assumes P
shows $eval\ cid\ t\ t'\ n\ (pred\ P)$
 <proof>

lemma $predE[elim]$:

fixes $cid\ t\ t'\ n\ P$
assumes $eval\ cid\ t\ t'\ n\ (pred\ P)$
shows P
 <proof>

2.4.2 True and False

abbreviation $true :: 'cmp\ bta$
where $true \equiv \lambda\ t\ n. HOL.True$

abbreviation $false :: 'cmp\ bta$
where $false \equiv \lambda\ t\ n. HOL.False$

2.4.3 Implication

definition $imp :: ('cmp\ bta) \Rightarrow ('cmp\ bta) \Rightarrow ('cmp\ bta)$ (**infixl** \longrightarrow^b 10)
where $\gamma \longrightarrow^b \gamma' \equiv \lambda\ t\ n. \gamma\ t\ n \longrightarrow \gamma'\ t\ n$

lemma $impI[intro!]$:

assumes $eval\ cid\ t\ t'\ n\ \gamma \longrightarrow eval\ cid\ t\ t'\ n\ \gamma'$
shows $eval\ cid\ t\ t'\ n\ (\gamma \longrightarrow^b \gamma')$
 <proof>

lemma $impE[elim!]$:

assumes $eval\ cid\ t\ t'\ n\ (\gamma \longrightarrow^b \gamma')$

shows $eval\ cid\ t\ t'\ n\ \gamma \longrightarrow eval\ cid\ t\ t'\ n\ \gamma'$
<proof>

2.4.4 Disjunction

definition $disj :: ('cmp\ bta) \Rightarrow ('cmp\ bta) \Rightarrow ('cmp\ bta)$ (**infixl** \vee^b 15)
where $\gamma \vee^b \gamma' \equiv \lambda\ t\ n.\ \gamma\ t\ n\ \vee\ \gamma'\ t\ n$

lemma $disjI[intro!]$:
assumes $eval\ cid\ t\ t'\ n\ \gamma \vee eval\ cid\ t\ t'\ n\ \gamma'$
shows $eval\ cid\ t\ t'\ n\ (\gamma \vee^b \gamma')$
<proof>

lemma $disjE[elim!]$:
assumes $eval\ cid\ t\ t'\ n\ (\gamma \vee^b \gamma')$
shows $eval\ cid\ t\ t'\ n\ \gamma \vee eval\ cid\ t\ t'\ n\ \gamma'$
<proof>

2.4.5 Conjunction

definition $conj :: ('cmp\ bta) \Rightarrow ('cmp\ bta) \Rightarrow ('cmp\ bta)$ (**infixl** \wedge^b 20)
where $\gamma \wedge^b \gamma' \equiv \lambda\ t\ n.\ \gamma\ t\ n\ \wedge\ \gamma'\ t\ n$

lemma $conjI[intro!]$:
assumes $eval\ cid\ t\ t'\ n\ \gamma \wedge eval\ cid\ t\ t'\ n\ \gamma'$
shows $eval\ cid\ t\ t'\ n\ (\gamma \wedge^b \gamma')$
<proof>

lemma $conjE[elim!]$:
assumes $eval\ cid\ t\ t'\ n\ (\gamma \wedge^b \gamma')$
shows $eval\ cid\ t\ t'\ n\ \gamma \wedge eval\ cid\ t\ t'\ n\ \gamma'$
<proof>

2.4.6 Negation

definition $neg :: ('cmp\ bta) \Rightarrow ('cmp\ bta)$ (\neg^b - [19] 19)
where $\neg^b \gamma \equiv \lambda\ t\ n.\ \neg\ \gamma\ t\ n$

lemma $negI[intro!]$:
assumes $\neg\ eval\ cid\ t\ t'\ n\ \gamma$
shows $eval\ cid\ t\ t'\ n\ (\neg^b \gamma)$
<proof>

lemma $negE[elim!]$:
assumes $eval\ cid\ t\ t'\ n\ (\neg^b \gamma)$
shows $\neg\ eval\ cid\ t\ t'\ n\ \gamma$
<proof>

2.4.7 Quantifiers

definition $all :: ('a \Rightarrow ('cmp\ bta))$
 $\Rightarrow ('cmp\ bta)$ (**binder** \forall_b 10)
where $all\ P \equiv \lambda\ t\ n.\ (\forall y.\ (P\ y\ t\ n))$

lemma $allI[intro!]$:
assumes $\forall p.\ eval\ cid\ t\ t'\ n\ (\gamma\ p)$

shows $eval\ cid\ t\ t'\ n\ (all\ (\lambda p.\ \gamma\ p))$
 $\langle proof \rangle$

lemma $allE[elim!]$:
assumes $eval\ cid\ t\ t'\ n\ (all\ (\lambda p.\ \gamma\ p))$
shows $\forall p.\ eval\ cid\ t\ t'\ n\ (\gamma\ p)$
 $\langle proof \rangle$

definition $ex :: ('a \Rightarrow ('cmp\ bta))$
 $\Rightarrow ('cmp\ bta)\ (binder\ \exists_b\ 10)$
where $ex\ P \equiv \lambda t\ n.\ (\exists y.\ (P\ y\ t\ n))$

lemma $exI[intro!]$:
assumes $\exists p.\ eval\ cid\ t\ t'\ n\ (\gamma\ p)$
shows $eval\ cid\ t\ t'\ n\ (\exists_b p.\ \gamma\ p)$
 $\langle proof \rangle$

lemma $exE[elim!]$:
assumes $eval\ cid\ t\ t'\ n\ (\exists_b p.\ \gamma\ p)$
shows $\exists p.\ eval\ cid\ t\ t'\ n\ (\gamma\ p)$
 $\langle proof \rangle$

2.4.8 Behavior Assertions

First we provide rules for basic behavior assertions.

definition $ba :: ('cmp \Rightarrow bool) \Rightarrow ('cmp\ bta)\ ([-]_b)$
where $ba\ \varphi \equiv \lambda t\ n.\ \varphi\ (t\ n)$

lemma $baIA[intro]$:
fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
assumes $\exists i \geq n.\ \|c\|_t\ i$
and $\varphi\ (\sigma_c(t\ \langle c \rightarrow t \rangle n))$
shows $eval\ c\ t\ t'\ n\ (ba\ \varphi)$
 $\langle proof \rangle$

lemma $baIN1[intro]$:
fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
assumes $act: \exists i.\ \|c\|_t\ i$
and $nAct: \nexists i.\ i \geq n \wedge \|c\|_t\ i$
and $al: \varphi\ (t'\ (n - \langle c \wedge t \rangle - 1))$
shows $eval\ c\ t\ t'\ n\ (ba\ \varphi)$
 $\langle proof \rangle$

lemma $baIN2[intro]$:
fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
assumes $nAct: \nexists i.\ \|c\|_t\ i$

and $al: \varphi (t' n)$
shows $eval\ c\ t\ t'\ n\ (ba\ \varphi)$
 $\langle proof \rangle$

lemma $baIANow[intro]$:
fixes $t\ n\ c\ \varphi$
assumes $\varphi (\sigma_c(t\ n))$
and $\|c\|_t\ n$
shows $eval\ c\ t\ t'\ n\ (ba\ \varphi)$
 $\langle proof \rangle$

lemma $baEA[elim]$:
fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
and $i::nat$
assumes $\exists i \geq n. \|c\|_t\ i$
and $eval\ c\ t\ t'\ n\ (ba\ \varphi)$
shows $\varphi (\sigma_c(t\ \langle c \rightarrow t \rangle n))$
 $\langle proof \rangle$

lemma $baEN1[elim]$:
fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
assumes $act: \exists i. \|c\|_t\ i$
and $nAct: \nexists i. i \geq n \wedge \|c\|_t\ i$
and $al: eval\ c\ t\ t'\ n\ (ba\ \varphi)$
shows $\varphi (t' (n - \langle c \wedge t \rangle - 1))$
 $\langle proof \rangle$

lemma $baEN2[elim]$:
fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
assumes $nAct: \nexists i. \|c\|_t\ i$
and $al: eval\ c\ t\ t'\ n\ (ba\ \varphi)$
shows $\varphi (t' n)$
 $\langle proof \rangle$

lemma $baEANow[elim]$:
fixes $t\ n\ c\ \varphi$
assumes $eval\ c\ t\ t'\ n\ (ba\ \varphi)$
and $\|c\|_t\ n$
shows $\varphi (\sigma_c(t\ n))$
 $\langle proof \rangle$

2.4.9 Next Operator

definition $next :: ('cmp\ bta) \Rightarrow ('cmp\ bta) (\circ_b(-)\ 24)$
where $\circ_b(\gamma) \equiv \lambda t\ n. \gamma\ t\ (Suc\ n)$

lemma $nextIA[intro]$:

fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
assumes $\exists i \geq n. \|c\|_t i$
and $\llbracket \exists i > \langle c \rightarrow t \rangle_n. \|c\|_t i \rrbracket \Longrightarrow \exists n' \geq n. (\exists ! i. n \leq i \wedge i < n' \wedge \|c\|_t i) \wedge eval\ c\ t\ t'\ n'\ \gamma$
and $\llbracket \neg(\exists i > \langle c \rightarrow t \rangle_n. \|c\|_t i) \rrbracket \Longrightarrow eval\ c\ t\ t'\ (Suc\ \langle c \rightarrow t \rangle_n)\ \gamma$
shows $eval\ c\ t\ t'\ n\ (\circ_b(\gamma))$
 $\langle proof \rangle$

lemma $nextIN[intro]$:
fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
assumes $\neg(\exists i \geq n. \|c\|_t i)$
and $eval\ c\ t\ t'\ (Suc\ n)\ \gamma$
shows $eval\ c\ t\ t'\ n\ (\circ_b(\gamma))$
 $\langle proof \rangle$

lemma $nextEA1[elim]$:
fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
assumes $\exists i > \langle c \rightarrow t \rangle_n. \|c\|_t i$
and $eval\ c\ t\ t'\ n\ (\circ_b(\gamma))$
and $n' \geq n$
and $\exists ! i. i \geq n \wedge i < n' \wedge \|c\|_t i$
shows $eval\ c\ t\ t'\ n'\ \gamma$
 $\langle proof \rangle$

lemma $nextEA2[elim]$:
fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
and i
assumes $\exists i \geq n. \|c\|_t i$ **and** $\neg(\exists i > \langle c \rightarrow t \rangle_n. \|c\|_t i)$
and $eval\ c\ t\ t'\ n\ (\circ_b(\gamma))$
shows $eval\ c\ t\ t'\ (Suc\ \langle c \rightarrow t \rangle_n)\ \gamma$
 $\langle proof \rangle$

lemma $nextEN[elim]$:
fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
assumes $\neg(\exists i \geq n. \|c\|_t i)$
and $eval\ c\ t\ t'\ n\ (\circ_b(\gamma))$
shows $eval\ c\ t\ t'\ (Suc\ n)\ \gamma$
 $\langle proof \rangle$

2.4.10 Eventually Operator

definition $evt :: ('cmp\ bta) \Rightarrow ('cmp\ bta) (\diamond_b(-)\ 23)$

where $\diamond_b(\gamma) \equiv \lambda t n. \exists n' \geq n. \gamma t n'$

lemma *evtIA*[*intro*]:

fixes $c::'id$

and $t::nat \Rightarrow cnf$

and $t'::nat \Rightarrow 'cmp$

and $n::nat$

and $n'::nat$

assumes $\exists i \geq n. \|c\|_t i$

and $n' \geq \langle c \Leftarrow t \rangle_n$

and $\llbracket \exists i \geq n'. \|c\|_{t' i} \rrbracket \Longrightarrow \exists n'' \geq \langle c \Leftarrow t \rangle_{n'}. n'' \leq \langle c \rightarrow t \rangle_{n'} \wedge eval\ c\ t\ t'\ n''\ \gamma$

and $\llbracket \neg(\exists i \geq n'. \|c\|_{t' i}) \rrbracket \Longrightarrow eval\ c\ t\ t'\ n'\ \gamma$

shows $eval\ c\ t\ t'\ n\ (\diamond_b(\gamma))$

<proof>

lemma *evtIN*[*intro*]:

fixes $c::'id$

and $t::nat \Rightarrow cnf$

and $t'::nat \Rightarrow 'cmp$

and $n::nat$

and $n'::nat$

assumes $\neg(\exists i \geq n. \|c\|_t i)$

and $n' \geq n$

and $eval\ c\ t\ t'\ n'\ \gamma$

shows $eval\ c\ t\ t'\ n\ (\diamond_b(\gamma))$

<proof>

lemma *evtEA*[*elim*]:

fixes $c::'id$

and $t::nat \Rightarrow cnf$

and $t'::nat \Rightarrow 'cmp$

and $n::nat$

assumes $\exists i \geq n. \|c\|_t i$

and $eval\ c\ t\ t'\ n\ (\diamond_b(\gamma))$

shows $\exists n' \geq \langle c \rightarrow t \rangle_n.$

$(\exists i \geq n'. \|c\|_{t' i} \wedge (\forall n'' \geq \langle c \Leftarrow t \rangle_{n'}. n'' \leq \langle c \rightarrow t \rangle_{n'} \longrightarrow eval\ c\ t\ t'\ n''\ \gamma)) \vee$

$(\neg(\exists i \geq n'. \|c\|_{t' i}) \wedge eval\ c\ t\ t'\ n'\ \gamma)$

<proof>

lemma *evtEN*[*elim*]:

fixes $c::'id$

and $t::nat \Rightarrow cnf$

and $t'::nat \Rightarrow 'cmp$

and $n::nat$

and $n'::nat$

assumes $\neg(\exists i \geq n. \|c\|_t i)$

and $eval\ c\ t\ t'\ n\ (\diamond_b(\gamma))$

shows $\exists n' \geq n. eval\ c\ t\ t'\ n'\ \gamma$

<proof>

2.4.11 Globally Operator

definition *glob* :: $('cmp\ bta) \Rightarrow ('cmp\ bta) (\square_b(-)\ 22)$

where $\square_b(\gamma) \equiv \lambda t n. \forall n' \geq n. \gamma t n'$

lemma *globIA*[*intro*]:

fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
assumes $\exists i \geq n. \|c\|_t i$
and $\bigwedge n'. \llbracket \exists i \geq n'. \|c\|_t i; n' \geq \langle c \rightarrow t \rangle_n \rrbracket \Longrightarrow \exists n'' \geq \langle c \leftarrow t \rangle_{n'}. n'' \leq \langle c \rightarrow t \rangle_{n'} \wedge eval\ c\ t\ t'\ n''\ \gamma$
and $\bigwedge n'. \llbracket \neg(\exists i \geq n'. \|c\|_t i); n' \geq \langle c \rightarrow t \rangle_n \rrbracket \Longrightarrow eval\ c\ t\ t'\ n'\ \gamma$
shows $eval\ c\ t\ t'\ n\ (\Box_b(\gamma))$
 $\langle proof \rangle$

lemma *globIN*[*intro*]:
fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
assumes $\neg(\exists i \geq n. \|c\|_t i)$
and $\bigwedge n'. n' \geq n \Longrightarrow eval\ c\ t\ t'\ n'\ \gamma$
shows $eval\ c\ t\ t'\ n\ (\Box_b(\gamma))$
 $\langle proof \rangle$

lemma *globEA*[*elim*]:
fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
and $n'::nat$
assumes $\exists i \geq n. \|c\|_t i$
and $eval\ c\ t\ t'\ n\ (\Box_b(\gamma))$
and $n' \geq \langle c \leftarrow t \rangle_n$
shows $eval\ c\ t\ t'\ n'\ \gamma$
 $\langle proof \rangle$

lemma *globEANow*:
fixes $c\ t\ t'\ n\ i\ \gamma$
assumes $n \leq i$
and $\|c\|_t i$
and $eval\ c\ t\ t'\ n\ (\Box_b\ \gamma)$
shows $eval\ c\ t\ t'\ i\ \gamma$
 $\langle proof \rangle$

lemma *globEN*[*elim*]:
fixes $c::'id$
and $t::nat \Rightarrow cnf$
and $t'::nat \Rightarrow 'cmp$
and $n::nat$
and $n'::nat$
assumes $\neg(\exists i \geq n. \|c\|_t i)$
and $eval\ c\ t\ t'\ n\ (\Box_b(\gamma))$
and $n' \geq n$
shows $eval\ c\ t\ t'\ n'\ \gamma$
 $\langle proof \rangle$

2.4.12 Until Operator

definition $until :: ('cmp\ bta) \Rightarrow ('cmp\ bta) \Rightarrow ('cmp\ bta)$ (**infixl** $\mathfrak{U}_b\ 21$)
where $\gamma' \mathfrak{U}_b\ \gamma \equiv \lambda\ t\ n. \exists n'' \geq n. \gamma\ t\ n'' \wedge (\forall n' \geq n. n' < n'' \longrightarrow \gamma'\ t\ n')$

lemma *untilIA*[*intro*]:

fixes $c::'id$

and $t::nat \Rightarrow cnf$

and $t'::nat \Rightarrow 'cmp$

and $n::nat$

and $n'::nat$

assumes $\exists i \geq n. \|c\|_t i$

and $n' \geq \langle c \Leftarrow t \rangle_n$

and $\llbracket \exists i \geq n'. \|c\|_t i \rrbracket \Longrightarrow \exists n'' \geq \langle c \Leftarrow t \rangle_{n'}. n'' \leq \langle c \rightarrow t \rangle_{n'} \wedge eval\ c\ t\ t'\ n''\ \gamma \wedge$

$(\forall n''' \geq \langle c \rightarrow t \rangle_n. n''' < \langle c \Leftarrow t \rangle_{n''}$

$\rightarrow (\exists n'''' \geq \langle c \Leftarrow t \rangle_{n''}. n'''' \leq \langle c \rightarrow t \rangle_{n''''} \wedge eval\ c\ t\ t'\ n''''\ \gamma')$

and $\llbracket \neg(\exists i \geq n'. \|c\|_t i) \rrbracket \Longrightarrow eval\ c\ t\ t'\ n'\ \gamma \wedge$

$(\forall n'' \geq \langle c \rightarrow t \rangle_n. n'' < n'$

$\rightarrow ((\exists i \geq n''. \|c\|_t i) \wedge (\exists n''' \geq \langle c \Leftarrow t \rangle_{n''}. n''' \leq \langle c \rightarrow t \rangle_{n''} \wedge eval\ c\ t\ t'\ n''' \gamma')) \vee$

$(\neg(\exists i \geq n''. \|c\|_t i) \wedge eval\ c\ t\ t'\ n''\ \gamma')$

shows $eval\ c\ t\ t'\ n\ (\gamma' \mathfrak{L}_b \gamma)$

<proof>

lemma *untilIN*[*intro*]:

fixes $c::'id$

and $t::nat \Rightarrow cnf$

and $t'::nat \Rightarrow 'cmp$

and $n::nat$

and $n'::nat$

assumes $\neg(\exists i \geq n. \|c\|_t i)$

and $n' \geq n$

and $eval\ c\ t\ t'\ n'\ \gamma$

and $a1: \bigwedge n''. \llbracket n \leq n''; n'' < n \rrbracket \Longrightarrow eval\ c\ t\ t'\ n''\ \gamma'$

shows $eval\ c\ t\ t'\ n\ (\gamma' \mathfrak{L}_b \gamma)$

<proof>

lemma *untilEA*[*elim*]:

fixes $n::nat$

and $n'::nat$

and $t::nat \Rightarrow cnf$

and $t'::nat \Rightarrow 'cmp$

and $c::'id$

assumes $\exists i \geq n. \|c\|_t i$

and $eval\ c\ t\ t'\ n\ (\gamma' \mathfrak{L}_b \gamma)$

shows $\exists n' \geq \langle c \rightarrow t \rangle_n.$

$((\exists i \geq n'. \|c\|_t i) \wedge (\forall n'' \geq \langle c \Leftarrow t \rangle_{n'}. n'' \leq \langle c \rightarrow t \rangle_{n'} \rightarrow eval\ c\ t\ t'\ n''\ \gamma)$

$\wedge (\forall n'' \geq \langle c \Leftarrow t \rangle_n. n'' < \langle c \Leftarrow t \rangle_{n'} \rightarrow eval\ c\ t\ t'\ n''\ \gamma') \vee$

$(\neg(\exists i \geq n'. \|c\|_t i) \wedge eval\ c\ t\ t'\ n'\ \gamma \wedge (\forall n'' \geq \langle c \Leftarrow t \rangle_n. n'' < n' \rightarrow eval\ c\ t\ t'\ n''\ \gamma'))$

<proof>

lemma *untilEN*[*elim*]:

fixes $n::nat$

and $n'::nat$

and $t::nat \Rightarrow cnf$

and $t'::nat \Rightarrow 'cmp$

and $c::'id$

assumes $\#i. i \geq n \wedge \|c\|_t i$

and $eval\ c\ t\ t'\ n\ (\gamma' \mathfrak{L}_b \gamma)$

shows $\exists n' \geq n. eval\ c\ t\ t'\ n'\ \gamma \wedge$

$(\forall n'' \geq n. n'' < n' \longrightarrow eval\ c\ t\ t'\ n''\ \gamma')$
 <proof>

2.4.13 Weak Until

definition $wuntil :: ('cmp\ bta) \Rightarrow ('cmp\ bta) \Rightarrow ('cmp\ bta)$ (**infixl** $\mathfrak{W}_b\ 20$)
 where $\gamma' \mathfrak{W}_b \gamma \equiv \gamma' \mathfrak{U}_b \gamma \vee^b \square_b(\gamma')$

end

end

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