

Nominal 2

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Abstract

Dealing with binders, renaming of bound variables, capture-avoiding substitution, etc., is very often a major problem in formal proofs, especially in proofs by structural and rule induction. Nominal Isabelle is designed to make such proofs easy to formalise: it provides an infrastructure for declaring nominal datatypes (that is alpha-equivalence classes) and for defining functions over them by structural recursion. It also provides induction principles that have Barendregts variable convention already built in.

This entry can be used as a more advanced replacement for HOL/Nominal in the Isabelle distribution.

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```

theory Nominal2-Base
imports HOL-Library.Infinite-Set
         HOL-Library.Multiset
         HOL-Library.FSet
         FinFun.FinFun
keywords
  atom-decl equivariance :: thy-decl
begin

declare [[typedef-overloaded]]

```

1 Atoms and Sorts

A simple implementation for *atom-sorts* is strings.

To deal with Church-like binding we use trees of strings as sorts.

```
datatype atom-sort = Sort string atom-sort list
```

```
datatype atom = Atom atom-sort nat
```

Basic projection function.

```
primrec
  sort-of :: atom  $\Rightarrow$  atom-sort
where
  sort-of (Atom s n) = s
```

```
primrec
  nat-of :: atom  $\Rightarrow$  nat
where
  nat-of (Atom s n) = n
```

There are infinitely many atoms of each sort.

```
lemma INFM-sort-of-eq:
shows INFM a. sort-of a = s
proof –
  have INFM i. sort-of (Atom s i) = s by simp
  moreover have inj (Atom s) by (simp add: inj-on-def)
  ultimately show INFM a. sort-of a = s by (rule INFM-inj)
qed
```

```
lemma infinite-sort-of-eq:
shows infinite {a. sort-of a = s}
```

using *INFM-sort-of-eq* **unfolding** *INFM-iff-infinite* .

lemma *atom-infinite* [*simp*]:
shows *infinite* (*UNIV* :: *atom set*)
using *subset-UNIV infinite-sort-of-eq*
by (*rule infinite-super*)

lemma *obtain-atom*:
fixes *X* :: *atom set*
assumes *X*: *finite X*
obtains *a* where $a \notin X$ *sort-of a = s*
proof –
from *X* have *MOST a. a* $\notin X$
unfolding *MOST-iff-cofinite* by *simp*
with *INFM-sort-of-eq*
have *INFM a. sort-of a = s* $\wedge a \notin X$
by (*rule INFM-conjI*)
then obtain *a* where $a \notin X$ *sort-of a = s*
by (*auto elim: INFM-E*)
then show *?thesis ..*
qed

lemma *atom-components-eq-iff*:
fixes *a b* :: *atom*
shows $a = b \iff \text{sort-of } a = \text{sort-of } b \wedge \text{nat-of } a = \text{nat-of } b$
by (*induct a, induct b, simp*)

2 Sort-Respecting Permutations

definition
 $\text{perm} \equiv \{f. \text{bij } f \wedge \text{finite } \{a. f\ a \neq a\} \wedge (\forall a. \text{sort-of } (f\ a) = \text{sort-of } a)\}$

typedef *perm* = *perm*
proof
show $id \in \text{perm}$ **unfolding** *perm-def* by *simp*
qed

lemma *permI*:
assumes *bij f* and *MOST x. f x = x* and $\bigwedge a. \text{sort-of } (f\ a) = \text{sort-of } a$
shows $f \in \text{perm}$
using *assms* **unfolding** *perm-def MOST-iff-cofinite* by *simp*

lemma *perm-is-bij*: $f \in \text{perm} \implies \text{bij } f$
unfolding *perm-def* by *simp*

lemma *perm-is-finite*: $f \in \text{perm} \implies \text{finite } \{a. f\ a \neq a\}$
unfolding *perm-def* by *simp*

lemma *perm-is-sort-respecting*: $f \in \text{perm} \implies \text{sort-of } (f\ a) = \text{sort-of } a$

unfolding *perm-def* **by** *simp*

lemma *perm-MOST*: $f \in \text{perm} \implies \text{MOST } x. f x = x$
unfolding *perm-def MOST-iff-cofinite* **by** *simp*

lemma *perm-id*: $\text{id} \in \text{perm}$
unfolding *perm-def* **by** *simp*

lemma *perm-comp*:
assumes $f: f \in \text{perm}$ **and** $g: g \in \text{perm}$
shows $(f \circ g) \in \text{perm}$
apply (*rule permI*)
apply (*rule bij-comp*)
apply (*rule perm-is-bij* [*OF g*])
apply (*rule perm-is-bij* [*OF f*])
apply (*rule MOST-rev-mp* [*OF perm-MOST* [*OF g*]])
apply (*rule MOST-rev-mp* [*OF perm-MOST* [*OF f*]])
apply (*simp*)
apply (*simp add: perm-is-sort-respecting* [*OF f*])
apply (*simp add: perm-is-sort-respecting* [*OF g*])
done

lemma *perm-inv*:
assumes $f: f \in \text{perm}$
shows $(\text{inv } f) \in \text{perm}$
apply (*rule permI*)
apply (*rule bij-imp-bij-inv*)
apply (*rule perm-is-bij* [*OF f*])
apply (*rule MOST-mono* [*OF perm-MOST* [*OF f*]])
apply (*erule subst, rule inv-f-f*)
apply (*rule bij-is-inj* [*OF perm-is-bij* [*OF f*]])
apply (*rule perm-is-sort-respecting* [*OF f*, *THEN sym*, *THEN trans*])
apply (*simp add: surj-f-inv-f* [*OF bij-is-surj* [*OF perm-is-bij* [*OF f*]]])
done

lemma *bij-Rep-perm*: $\text{bij } (\text{Rep-perm } p)$
using *Rep-perm* [*of p*] **unfolding** *perm-def* **by** *simp*

lemma *finite-Rep-perm*: $\text{finite } \{a. \text{Rep-perm } p a \neq a\}$
using *Rep-perm* [*of p*] **unfolding** *perm-def* **by** *simp*

lemma *sort-of-Rep-perm*: $\text{sort-of } (\text{Rep-perm } p a) = \text{sort-of } a$
using *Rep-perm* [*of p*] **unfolding** *perm-def* **by** *simp*

lemma *Rep-perm-ext*:
 $\text{Rep-perm } p1 = \text{Rep-perm } p2 \implies p1 = p2$
by (*simp add: fun-eq-iff Rep-perm-inject* [*symmetric*])

instance *perm* :: *size* ..

2.1 Permutations form a (multiplicative) group

instantiation *perm* :: *group-add*

begin

definition

$0 = \text{Abs-perm } id$

definition

$- p = \text{Abs-perm } (\text{inv } (\text{Rep-perm } p))$

definition

$p + q = \text{Abs-perm } (\text{Rep-perm } p \circ \text{Rep-perm } q)$

definition

$(p1 :: \text{perm}) - p2 = p1 + - p2$

lemma *Rep-perm-0*: $\text{Rep-perm } 0 = id$

unfolding *zero-perm-def*

by (*simp add: Abs-perm-inverse perm-id*)

lemma *Rep-perm-add*:

$\text{Rep-perm } (p1 + p2) = \text{Rep-perm } p1 \circ \text{Rep-perm } p2$

unfolding *plus-perm-def*

by (*simp add: Abs-perm-inverse perm-comp Rep-perm*)

lemma *Rep-perm-uminus*:

$\text{Rep-perm } (- p) = \text{inv } (\text{Rep-perm } p)$

unfolding *uminus-perm-def*

by (*simp add: Abs-perm-inverse perm-inv Rep-perm*)

instance

apply *standard*

unfolding *Rep-perm-inject* [*symmetric*]

unfolding *minus-perm-def*

unfolding *Rep-perm-add*

unfolding *Rep-perm-uminus*

unfolding *Rep-perm-0*

by (*simp-all add: o-assoc inv-o-cancel [OF bij-is-inj [OF bij-Rep-perm]]*)

end

3 Implementation of swappings

definition

$\text{swap} :: \text{atom} \Rightarrow \text{atom} \Rightarrow \text{perm } (('(- \rightleftharpoons -'))$

where

$(a \rightleftharpoons b) =$

$\text{Abs-perm } (\text{if } \text{sort-of } a = \text{sort-of } b$

then ($\lambda c. \text{if } a = c \text{ then } b \text{ else if } b = c \text{ then } a \text{ else } c$)
 else id)

lemma *Rep-perm-swap*:

Rep-perm ($a \rightleftharpoons b$) =
 (if sort-of $a = \text{sort-of } b$
 then ($\lambda c. \text{if } a = c \text{ then } b \text{ else if } b = c \text{ then } a \text{ else } c$)
 else id)

unfolding *swap-def*

apply (rule *Abs-perm-inverse*)

apply (rule *permI*)

apply (auto simp: *bij-def inj-on-def surj-def*)[1]

apply (rule *MOST-rev-mp* [OF *MOST-neq(1)*] [of a])

apply (rule *MOST-rev-mp* [OF *MOST-neq(1)*] [of b])

apply (simp)

apply (simp)

done

lemmas *Rep-perm-simps* =

Rep-perm-0

Rep-perm-add

Rep-perm-uminus

Rep-perm-swap

lemma *swap-different-sorts* [simp]:

sort-of $a \neq \text{sort-of } b \implies (a \rightleftharpoons b) = 0$

by (rule *Rep-perm-ext*) (simp add: *Rep-perm-simps*)

lemma *swap-cancel*:

shows $(a \rightleftharpoons b) + (a \rightleftharpoons b) = 0$

and $(a \rightleftharpoons b) + (b \rightleftharpoons a) = 0$

by (rule-tac [!] *Rep-perm-ext*)

(simp-all add: *Rep-perm-simps fun-eq-iff*)

lemma *swap-self* [simp]:

$(a \rightleftharpoons a) = 0$

by (rule *Rep-perm-ext*, simp add: *Rep-perm-simps fun-eq-iff*)

lemma *minus-swap* [simp]:

$-(a \rightleftharpoons b) = (a \rightleftharpoons b)$

by (rule *minus-unique* [OF *swap-cancel(1)*])

lemma *swap-commute*:

$(a \rightleftharpoons b) = (b \rightleftharpoons a)$

by (rule *Rep-perm-ext*)

(simp add: *Rep-perm-swap fun-eq-iff*)

lemma *swap-triple*:

assumes $a \neq b$ **and** $c \neq b$


```

assumes sort-of a = sort-of b sort-of b = sort-of c
shows  $(a \rightleftharpoons c) + (b \rightleftharpoons c) + (a \rightleftharpoons c) = (a \rightleftharpoons b)$ 
using assms
by (rule-tac Rep-perm-ext)
      (auto simp: Rep-perm-simps fun-eq-iff)

```

4 Permutation Types

Infix syntax for *permute* has higher precedence than addition, but lower than unary minus.

```

class pt =
  fixes permute :: perm  $\Rightarrow$   $'a \Rightarrow 'a$  (- · - [76, 75] 75)
  assumes permute-zero [simp]:  $0 \cdot x = x$ 
  assumes permute-plus [simp]:  $(p + q) \cdot x = p \cdot (q \cdot x)$ 
begin

```

```

lemma permute-diff [simp]:
  shows  $(p - q) \cdot x = p \cdot - q \cdot x$ 
  using permute-plus [of p - q x] by simp

```

```

lemma permute-minus-cancel [simp]:
  shows  $p \cdot - p \cdot x = x$ 
  and  $- p \cdot p \cdot x = x$ 
  unfolding permute-plus [symmetric] by simp-all

```

```

lemma permute-swap-cancel [simp]:
  shows  $(a \rightleftharpoons b) \cdot (a \rightleftharpoons b) \cdot x = x$ 
  unfolding permute-plus [symmetric]
  by (simp add: swap-cancel)

```

```

lemma permute-swap-cancel2 [simp]:
  shows  $(a \rightleftharpoons b) \cdot (b \rightleftharpoons a) \cdot x = x$ 
  unfolding permute-plus [symmetric]
  by (simp add: swap-commute)

```

```

lemma inj-permute [simp]:
  shows inj (permute p)
  by (rule inj-on-inverseI)
      (rule permute-minus-cancel)

```

```

lemma surj-permute [simp]:
  shows surj (permute p)
  by (rule surjI, rule permute-minus-cancel)

```

```

lemma bij-permute [simp]:
  shows bij (permute p)
  by (rule bijI [OF inj-permute surj-permute])

```

lemma *inv-permute*:
shows $\text{inv} (\text{permute } p) = \text{permute } (- p)$
by (*rule inv-equality*) (*simp-all*)

lemma *permute-minus*:
shows $\text{permute } (- p) = \text{inv} (\text{permute } p)$
by (*simp add: inv-permute*)

lemma *permute-eq-iff* [*simp*]:
shows $p \cdot x = p \cdot y \iff x = y$
by (*rule inj-permute [THEN inj-eq]*)

end

4.1 Permutations for atoms

instantiation *atom* :: *pt*
begin

definition
 $p \cdot a = (\text{Rep-perm } p) a$

instance
apply *standard*
apply(*simp-all add: permute-atom-def Rep-perm-simps*)
done

end

lemma *sort-of-permute* [*simp*]:
shows $\text{sort-of } (p \cdot a) = \text{sort-of } a$
unfolding *permute-atom-def* **by** (*rule sort-of-Rep-perm*)

lemma *swap-atom*:
shows $(a \rightleftharpoons b) \cdot c =$
 (*if sort-of a = sort-of b*
 then (if c = a then b else if c = b then a else c) else c)
unfolding *permute-atom-def*
by (*simp add: Rep-perm-swap*)

lemma *swap-atom-simps* [*simp*]:
 $\text{sort-of } a = \text{sort-of } b \implies (a \rightleftharpoons b) \cdot a = b$
 $\text{sort-of } a = \text{sort-of } b \implies (a \rightleftharpoons b) \cdot b = a$
 $c \neq a \implies c \neq b \implies (a \rightleftharpoons b) \cdot c = c$
unfolding *swap-atom* **by** *simp-all*

lemma *perm-eq-iff*:
fixes $p q :: \text{perm}$
shows $p = q \iff (\forall a::\text{atom. } p \cdot a = q \cdot a)$

unfolding *permute-atom-def*
by (*metis Rep-perm-ext ext*)

4.2 Permutations for permutations

instantiation *perm* :: *pt*
begin

definition

$$p \cdot q = p + q - p$$

instance

apply *standard*
apply (*simp add: permute-perm-def*)
apply (*simp add: permute-perm-def algebra-simps*)
done

end

lemma *permute-self*:

shows $p \cdot p = p$
unfolding *permute-perm-def*
by (*simp add: add.assoc*)

lemma *permute-minus-self*:

shows $- p \cdot p = p$
unfolding *permute-perm-def*
by (*simp add: add.assoc*)

4.3 Permutations for functions

instantiation *fun* :: (*pt*, *pt*) *pt*
begin

definition

$$p \cdot f = (\lambda x. p \cdot (f (- p \cdot x)))$$

instance

apply *standard*
apply (*simp add: permute-fun-def*)
apply (*simp add: permute-fun-def minus-add*)
done

end

lemma *permute-fun-app-eq*:

shows $p \cdot (f x) = (p \cdot f) (p \cdot x)$
unfolding *permute-fun-def* **by** *simp*

lemma *permute-fun-comp*:

shows $p \cdot f = (\text{permute } p) \circ f \circ (\text{permute } (-p))$
by (*simp add: comp-def permute-fun-def*)

4.4 Permutations for booleans

instantiation $\text{bool} :: \text{pt}$
begin

definition $p \cdot (b::\text{bool}) = b$

instance
apply *standard*
apply(*simp-all add: permute-bool-def*)
done

end

lemma *permute-boolE*:
fixes $P::\text{bool}$
shows $p \cdot P \implies P$
by (*simp add: permute-bool-def*)

lemma *permute-boolI*:
fixes $P::\text{bool}$
shows $P \implies p \cdot P$
by(*simp add: permute-bool-def*)

4.5 Permutations for sets

instantiation $\text{set} :: (\text{pt}) \text{pt}$
begin

definition
 $p \cdot X = \{p \cdot x \mid x. x \in X\}$

instance
apply *standard*
apply (*auto simp: permute-set-def*)
done

end

lemma *permute-set-eq*:
shows $p \cdot X = \{x. - p \cdot x \in X\}$
unfolding *permute-set-def*
by (*auto*) (*metis permute-minus-cancel(1)*)

lemma *permute-set-eq-image*:
shows $p \cdot X = \text{permute } p \text{ ` } X$
unfolding *permute-set-def* **by** *auto*

lemma *permute-set-eq-vimage*:
shows $p \cdot X = \text{permute } (- p) -' X$
unfolding *permute-set-eq vimage-def*
by *simp*

lemma *permute-finite* [*simp*]:
shows $\text{finite } (p \cdot X) = \text{finite } X$
unfolding *permute-set-eq-vimage*
using *bij-permute* **by** (*rule finite-vimage-iff*)

lemma *swap-set-not-in*:
assumes $a: a \notin S \ b \notin S$
shows $(a \rightleftharpoons b) \cdot S = S$
unfolding *permute-set-def*
using a **by** (*auto simp: swap-atom*)

lemma *swap-set-in*:
assumes $a: a \in S \ b \notin S \ \text{sort-of } a = \text{sort-of } b$
shows $(a \rightleftharpoons b) \cdot S \neq S$
unfolding *permute-set-def*
using a **by** (*auto simp: swap-atom*)

lemma *swap-set-in-eq*:
assumes $a: a \in S \ b \notin S \ \text{sort-of } a = \text{sort-of } b$
shows $(a \rightleftharpoons b) \cdot S = (S - \{a\}) \cup \{b\}$
unfolding *permute-set-def*
using a **by** (*auto simp: swap-atom*)

lemma *swap-set-both-in*:
assumes $a: a \in S \ b \in S$
shows $(a \rightleftharpoons b) \cdot S = S$
unfolding *permute-set-def*
using a **by** (*auto simp: swap-atom*)

lemma *mem-permute-iff*:
shows $(p \cdot x) \in (p \cdot X) \longleftrightarrow x \in X$
unfolding *permute-set-def*
by *auto*

lemma *empty-eqt*:
shows $p \cdot \{\} = \{\}$
unfolding *permute-set-def*
by (*simp*)

lemma *insert-eqt*:
shows $p \cdot (\text{insert } x \ A) = \text{insert } (p \cdot x) \ (p \cdot A)$
unfolding *permute-set-eq-image image-insert ..*

4.6 Permutations for *unit*

instantiation *unit* :: *pt*
begin

definition $p \cdot (u::unit) = u$

instance
by *standard* (*simp-all add: permute-unit-def*)

end

4.7 Permutations for products

instantiation *prod* :: (*pt*, *pt*) *pt*
begin

primrec
 permute-prod
where
 Pair-eqvt: $p \cdot (x, y) = (p \cdot x, p \cdot y)$

instance
by *standard auto*

end

4.8 Permutations for sums

instantiation *sum* :: (*pt*, *pt*) *pt*
begin

primrec
 permute-sum
where
 Inl-eqvt: $p \cdot (Inl\ x) = Inl\ (p \cdot x)$
 | *Inr-eqvt*: $p \cdot (Inr\ y) = Inr\ (p \cdot y)$

instance
by *standard* (*case-tac* [!] *x*, *simp-all*)

end

4.9 Permutations for 'a list

instantiation *list* :: (*pt*) *pt*
begin

primrec
 permute-list

where
Nil-eqvt: $p \cdot [] = []$
| *Cons-eqvt*: $p \cdot (x \# xs) = p \cdot x \# p \cdot xs$

instance
by *standard* (*induct-tac* [!] *x*, *simp-all*)

end

lemma *set-eqvt*:
shows $p \cdot (\text{set } xs) = \text{set } (p \cdot xs)$
by (*induct* *xs*) (*simp-all* *add*: *empty-eqvt* *insert-eqvt*)

4.10 Permutations for 'a option

instantiation *option* :: (*pt*) *pt*
begin

primrec
permute-option

where
None-eqvt: $p \cdot \text{None} = \text{None}$
| *Some-eqvt*: $p \cdot (\text{Some } x) = \text{Some } (p \cdot x)$

instance
by *standard* (*induct-tac* [!] *x*, *simp-all*)

end

4.11 Permutations for 'a multiset

instantiation *multiset* :: (*pt*) *pt*
begin

definition
 $p \cdot M = \{\# p \cdot x. x \# M \#\}$

instance
proof
fix *M* :: 'a multiset and *p* *q* :: perm
show $0 \cdot M = M$
 unfolding *permute-multiset-def*
 by (*induct-tac* *M*) (*simp-all*)
show $(p + q) \cdot M = p \cdot q \cdot M$
 unfolding *permute-multiset-def*
 by (*induct-tac* *M*) (*simp-all*)
qed

end

```

lemma permute-multiset [simp]:
  fixes  $M N :: ('a :: pt) \text{multiset}$ 
  shows  $(p \cdot \{\#\}) = (\{\#\} :: ('a :: pt) \text{multiset})$ 
  and  $(p \cdot \text{add-mset } x M) = \text{add-mset } (p \cdot x) (p \cdot M)$ 
  and  $(p \cdot (M + N)) = (p \cdot M) + (p \cdot N)$ 
  unfolding permute-multiset-def
  by (simp-all)

```

4.12 Permutations for $'a$ fset

```

instantiation fset :: (pt) pt
begin

```

```

context includes fset.lifting begin

```

```

lift-definition

```

```

  permute-fset :: perm  $\Rightarrow 'a \text{ fset} \Rightarrow 'a \text{ fset}$ 
is permute :: perm  $\Rightarrow 'a \text{ set} \Rightarrow 'a \text{ set}$  by simp
end

```

```

context includes fset.lifting begin

```

```

instance

```

```

proof

```

```

  fix  $x :: 'a \text{ fset}$  and  $p q :: \text{perm}$ 
  show  $0 \cdot x = x$  by transfer simp
  show  $(p + q) \cdot x = p \cdot q \cdot x$  by transfer simp
qed
end

```

```

end

```

```

context includes fset.lifting

```

```

begin

```

```

lemma permute-fset [simp]:

```

```

  fixes  $S :: ('a :: pt) \text{fset}$ 
  shows  $(p \cdot \{\|\}) = (\{\|\} :: ('a :: pt) \text{fset})$ 
  and  $(p \cdot \text{finsert } x S) = \text{finsert } (p \cdot x) (p \cdot S)$ 
  apply (transfer, simp add: empty-eqvt)
  apply (transfer, simp add: insert-eqvt)
  done

```

```

lemma fset-eqvt:

```

```

  shows  $p \cdot (\text{fset } S) = \text{fset } (p \cdot S)$ 
  by transfer simp
end

```

4.13 Permutations for $('a, 'b)$ finfun

```

instantiation finfun :: (pt, pt) pt
begin

```


lift-definition

permute-funfun :: *perm* \Rightarrow ('a, 'b) *funfun* \Rightarrow ('a, 'b) *funfun*

is

permute :: *perm* \Rightarrow ('a \Rightarrow 'b) \Rightarrow ('a \Rightarrow 'b)

apply(*simp add: permute-fun-comp*)

apply(*rule funfun-right-compose*)

apply(*rule funfun-left-compose*)

apply(*assumption*)

apply(*simp*)

done

instance

apply *standard*

apply(*transfer*)

apply(*simp*)

apply(*transfer*)

apply(*simp*)

done

end

4.14 Permutations for char, nat, and int

instantiation *char* :: *pt*

begin

definition $p \cdot (c::char) = c$

instance

by *standard (simp-all add: permute-char-def)*

end

instantiation *nat* :: *pt*

begin

definition $p \cdot (n::nat) = n$

instance

by *standard (simp-all add: permute-nat-def)*

end

instantiation *int* :: *pt*

begin

definition $p \cdot (i::int) = i$

instance

by *standard* (*simp-all add: permute-int-def*)

end

5 Pure types

Pure types will have always empty support.

```
class pure = pt +  
  assumes permute-pure:  $p \cdot x = x$ 
```

Types *unit* and *bool* are pure.

```
instance unit :: pure  
proof qed (rule permute-unit-def)
```

```
instance bool :: pure  
proof qed (rule permute-bool-def)
```

Other type constructors preserve purity.

```
instance fun :: (pure, pure) pure  
by standard (simp add: permute-fun-def permute-pure)
```

```
instance set :: (pure) pure  
by standard (simp add: permute-set-def permute-pure)
```

```
instance prod :: (pure, pure) pure  
by standard (induct-tac x, simp add: permute-pure)
```

```
instance sum :: (pure, pure) pure  
by standard (induct-tac x, simp-all add: permute-pure)
```

```
instance list :: (pure) pure  
by standard (induct-tac x, simp-all add: permute-pure)
```

```
instance option :: (pure) pure  
by standard (induct-tac x, simp-all add: permute-pure)
```

5.1 Types *char*, *nat*, and *int*

```
instance char :: pure  
proof qed (rule permute-char-def)
```

```
instance nat :: pure  
proof qed (rule permute-nat-def)
```

```
instance int :: pure  
proof qed (rule permute-int-def)
```

6 Infrastructure for Equivariance and *Perm-simp*

6.1 Basic functions about permutations

ML-file \langle *nominal-basics.ML* \rangle

6.2 Eqvt infrastructure

Setup of the theorem attributes *eqvt* and *eqvt-raw*.

ML-file \langle *nominal-thmdecls.ML* \rangle

lemmas [*eqvt*] =

permute-prod.simps
permute-list.simps
permute-option.simps
permute-sum.simps

empty-eqvt insert-eqvt set-eqvt

permute-fset fset-eqvt

permute-multiset

6.3 *perm-simp* infrastructure

definition

unpermute $p = \text{permute } (-\ p)$

lemma *eqvt-apply*:

fixes $f :: 'a::pt \Rightarrow 'b::pt$

and $x :: 'a::pt$

shows $p \cdot (f\ x) \equiv (p \cdot f)\ (p \cdot x)$

unfolding *permute-fun-def* **by** *simp*

lemma *eqvt-lambda*:

fixes $f :: 'a::pt \Rightarrow 'b::pt$

shows $p \cdot f \equiv (\lambda x. p \cdot (f\ (\text{unpermute } p\ x)))$

unfolding *permute-fun-def unpermute-def* **by** *simp*

lemma *eqvt-bound*:

shows $p \cdot \text{unpermute } p\ x \equiv x$

unfolding *unpermute-def* **by** *simp*

provides *perm-simp* methods

ML-file \langle *nominal-permeq.ML* \rangle

```

method-setup perm-simp =
  ⟨Nominal-Permeq.args-parser >> Nominal-Permeq.perm-simp-meth⟩
  ⟨pushes permutations inside.⟩

method-setup perm-strict-simp =
  ⟨Nominal-Permeq.args-parser >> Nominal-Permeq.perm-strict-simp-meth⟩
  ⟨pushes permutations inside, raises an error if it cannot solve all permutations.⟩

simproc-setup perm-simproc (p · t) = ⟨fn - => fn ctxt => fn ctrm =>
  case Thm.term-of (Thm.dest-arg ctrm) of
    | Free - => NONE
    | Var - => NONE
    | Const-⟨permute - for - -> => NONE
    | - =>
      let
        val thm = Nominal-Permeq.eqt-conv ctxt Nominal-Permeq.eqt-strict-config
      ctrm
        handle ERROR - => Thm.reflexive ctrm
      in
        if Thm.is-reflexive thm then NONE else SOME(thm)
      end
  ⟩

```

6.3.1 Equivariance for permutations and swapping

```

lemma permute-eqt:
  shows  $p \cdot (q \cdot x) = (p \cdot q) \cdot (p \cdot x)$ 
  unfolding permute-perm-def by simp

```

```

lemma permute-eqt-raw [eqt-raw]:
  shows  $p \cdot \text{permute} \equiv \text{permute}$ 
apply(simp add: fun-eq-iff permute-fun-def)
apply(subst permute-eqt)
apply(simp)
done

```

```

lemma zero-perm-eqt [eqt]:
  shows  $p \cdot (0::perm) = 0$ 
  unfolding permute-perm-def by simp

```

```

lemma add-perm-eqt [eqt]:
  fixes p p1 p2 :: perm
  shows  $p \cdot (p1 + p2) = p \cdot p1 + p \cdot p2$ 
  unfolding permute-perm-def
  by (simp add: perm-eq-iff)

```

```

lemma swap-eqt [eqt]:

```

shows $p \cdot (a \rightleftharpoons b) = (p \cdot a \rightleftharpoons p \cdot b)$
unfolding *permute-perm-def*
by (*auto simp: swap-atom perm-eq-iff*)

lemma *uminus-eqvt* [*eqvt*]:
fixes $p q::\text{perm}$
shows $p \cdot (- q) = - (p \cdot q)$
unfolding *permute-perm-def*
by (*simp add: diff-add-eq-diff-diff-swap*)

6.3.2 Equivariance of Logical Operators

lemma *eq-eqvt* [*eqvt*]:
shows $p \cdot (x = y) \longleftrightarrow (p \cdot x) = (p \cdot y)$
unfolding *permute-eq-iff permute-bool-def ..*

lemma *Not-eqvt* [*eqvt*]:
shows $p \cdot (\neg A) \longleftrightarrow \neg (p \cdot A)$
by (*simp add: permute-bool-def*)

lemma *conj-eqvt* [*eqvt*]:
shows $p \cdot (A \wedge B) \longleftrightarrow (p \cdot A) \wedge (p \cdot B)$
by (*simp add: permute-bool-def*)

lemma *imp-eqvt* [*eqvt*]:
shows $p \cdot (A \longrightarrow B) \longleftrightarrow (p \cdot A) \longrightarrow (p \cdot B)$
by (*simp add: permute-bool-def*)

declare *imp-eqvt*[*folded HOL.induct-implies-def, eqvt*]

lemma *all-eqvt* [*eqvt*]:
shows $p \cdot (\forall x. P x) = (\forall x. (p \cdot P) x)$
unfolding *All-def*
by (*perm-simp*) (*rule refl*)

declare *all-eqvt*[*folded HOL.induct-forall-def, eqvt*]

lemma *ex-eqvt* [*eqvt*]:
shows $p \cdot (\exists x. P x) = (\exists x. (p \cdot P) x)$
unfolding *Ex-def*
by (*perm-simp*) (*rule refl*)

lemma *ex1-eqvt* [*eqvt*]:
shows $p \cdot (\exists!x. P x) = (\exists!x. (p \cdot P) x)$
unfolding *Ex1-def*
by (*perm-simp*) (*rule refl*)

lemma *if-eqvt* [*eqvt*]:
shows $p \cdot (\text{if } b \text{ then } x \text{ else } y) = (\text{if } p \cdot b \text{ then } p \cdot x \text{ else } p \cdot y)$

by (*simp add: permute-fun-def permute-bool-def*)

lemma *True-eqvt* [*eqvt*]:
shows $p \cdot \text{True} = \text{True}$
unfolding *permute-bool-def* ..

lemma *False-eqvt* [*eqvt*]:
shows $p \cdot \text{False} = \text{False}$
unfolding *permute-bool-def* ..

lemma *disj-eqvt* [*eqvt*]:
shows $p \cdot (A \vee B) \longleftrightarrow (p \cdot A) \vee (p \cdot B)$
by (*simp add: permute-bool-def*)

lemma *all-eqvt2*:
shows $p \cdot (\forall x. P x) = (\forall x. p \cdot P (- p \cdot x))$
by (*perm-simp add: permute-minus-cancel*) (*rule refl*)

lemma *ex-eqvt2*:
shows $p \cdot (\exists x. P x) = (\exists x. p \cdot P (- p \cdot x))$
by (*perm-simp add: permute-minus-cancel*) (*rule refl*)

lemma *ex1-eqvt2*:
shows $p \cdot (\exists!x. P x) = (\exists!x. p \cdot P (- p \cdot x))$
by (*perm-simp add: permute-minus-cancel*) (*rule refl*)

lemma *the-eqvt*:
assumes *unique*: $\exists!x. P x$
shows $(p \cdot (\text{THE } x. P x)) = (\text{THE } x. (p \cdot P) x)$
apply(*rule the1-equality [symmetric]*)
apply(*rule-tac p=-p in permute-boolE*)
apply(*perm-simp add: permute-minus-cancel*)
apply(*rule unique*)
apply(*rule-tac p=-p in permute-boolE*)
apply(*perm-simp add: permute-minus-cancel*)
apply(*rule theI'[OF unique]*)
done

lemma *the-eqvt2*:
assumes *unique*: $\exists!x. P x$
shows $(p \cdot (\text{THE } x. P x)) = (\text{THE } x. p \cdot P (- p \cdot x))$
apply(*rule the1-equality [symmetric]*)
apply(*simp only: ex1-eqvt2[symmetric]*)
apply(*simp add: permute-bool-def unique*)
apply(*simp add: permute-bool-def*)
apply(*rule theI'[OF unique]*)
done

6.3.3 Equivariance of Set operators

lemma *mem-eqvt* [eqvt]:

shows $p \cdot (x \in A) \longleftrightarrow (p \cdot x) \in (p \cdot A)$

unfolding *permute-bool-def permute-set-def*

by (*auto*)

lemma *Collect-eqvt* [eqvt]:

shows $p \cdot \{x. P x\} = \{x. (p \cdot P) x\}$

unfolding *permute-set-eq permute-fun-def*

by (*auto simp: permute-bool-def*)

lemma *Bex-eqvt* [eqvt]:

shows $p \cdot (\exists x \in S. P x) = (\exists x \in (p \cdot S). (p \cdot P) x)$

unfolding *Bex-def* **by** *simp*

lemma *Ball-eqvt* [eqvt]:

shows $p \cdot (\forall x \in S. P x) = (\forall x \in (p \cdot S). (p \cdot P) x)$

unfolding *Ball-def* **by** *simp*

lemma *image-eqvt* [eqvt]:

shows $p \cdot (f \text{ ` } A) = (p \cdot f) \text{ ` } (p \cdot A)$

unfolding *image-def* **by** *simp*

lemma *Image-eqvt* [eqvt]:

shows $p \cdot (R \text{ `` } A) = (p \cdot R) \text{ `` } (p \cdot A)$

unfolding *Image-def* **by** *simp*

lemma *UNIV-eqvt* [eqvt]:

shows $p \cdot UNIV = UNIV$

unfolding *UNIV-def*

by (*perm-simp*) (*rule refl*)

lemma *inter-eqvt* [eqvt]:

shows $p \cdot (A \cap B) = (p \cdot A) \cap (p \cdot B)$

unfolding *Int-def* **by** *simp*

lemma *Inter-eqvt* [eqvt]:

shows $p \cdot \bigcap S = \bigcap (p \cdot S)$

unfolding *Inter-eq* **by** *simp*

lemma *union-eqvt* [eqvt]:

shows $p \cdot (A \cup B) = (p \cdot A) \cup (p \cdot B)$

unfolding *Un-def* **by** *simp*

lemma *Union-eqvt* [eqvt]:

shows $p \cdot \bigcup A = \bigcup (p \cdot A)$

unfolding *Union-eq*

by *perm-simp rule*

lemma *Diff-eqvt* [eqvt]:
fixes $A B :: 'a::pt\ set$
shows $p \cdot (A - B) = (p \cdot A) - (p \cdot B)$
unfolding *set-diff-eq* **by** *simp*

lemma *Compl-eqvt* [eqvt]:
fixes $A :: 'a::pt\ set$
shows $p \cdot (- A) = - (p \cdot A)$
unfolding *Compl-eq-Diff-UNIV* **by** *simp*

lemma *subset-eqvt* [eqvt]:
shows $p \cdot (S \subseteq T) \longleftrightarrow (p \cdot S) \subseteq (p \cdot T)$
unfolding *subset-eq* **by** *simp*

lemma *psubset-eqvt* [eqvt]:
shows $p \cdot (S \subset T) \longleftrightarrow (p \cdot S) \subset (p \cdot T)$
unfolding *psubset-eq* **by** *simp*

lemma *vimage-eqvt* [eqvt]:
shows $p \cdot (f -^{\cdot} A) = (p \cdot f) -^{\cdot} (p \cdot A)$
unfolding *vimage-def* **by** *simp*

lemma *foldr-eqvt*[eqvt]:
 $p \cdot \text{foldr } f \ xs = \text{foldr } (p \cdot f) \ (p \cdot xs)$
apply(*induct xs*)
apply(*simp-all*)
apply(*perm-simp exclude: foldr*)
apply(*simp*)
done

lemma *Sigma-eqvt*:
shows $p \cdot (X \times Y) = (p \cdot X) \times (p \cdot Y)$
unfolding *Sigma-def*
by (*perm-simp*) (*rule refl*)

In order to prove that *lfp* is equivariant we need two auxiliary classes which specify that (*<=*) and *Inf* are equivariant. Instances for *bool* and *fun* are given.

class *le-eqvt* = *pt* +
assumes *le-eqvt* [eqvt]: $p \cdot (x \leq y) = ((p \cdot x) \leq (p \cdot (y :: 'a :: \{order, pt\})))$

class *inf-eqvt* = *pt* +
assumes *inf-eqvt* [eqvt]: $p \cdot (\text{Inf } X) = \text{Inf } (p \cdot (X :: 'a :: \{complete-lattice, pt\} set))$

instantiation *bool* :: *le-eqvt*
begin


```

instance
  apply standard
  unfolding le-bool-def
  apply(perm-simp)
  apply(rule refl)
  done

end

instantiation fun :: (pt, le-eqvt) le-eqvt
begin

  instance
    apply standard
    unfolding le-fun-def
    apply(perm-simp)
    apply(rule refl)
    done

  end

  instantiation bool :: inf-eqvt
  begin

    instance
      apply standard
      unfolding Inf-bool-def
      apply(perm-simp)
      apply(rule refl)
      done

    end

    instantiation fun :: (pt, inf-eqvt) inf-eqvt
    begin

      instance
        apply standard
        unfolding Inf-fun-def
        apply(perm-simp)
        apply(rule refl)
        done

      end

      lemma lfp-eqvt [eqvt]:
        fixes F::('a ⇒ 'b) ⇒ ('a::pt ⇒ 'b::{inf-eqvt, le-eqvt})
        shows p · (lfp F) = lfp (p · F)
      unfolding lfp-def

```

by *simp*

lemma *finite-eqvt* [*eqvt*]:
 shows $p \cdot \text{finite } A = \text{finite } (p \cdot A)$
unfolding *finite-def*
by *simp*

lemma *fun-upd-eqvt*[*eqvt*]:
 shows $p \cdot (f(x := y)) = (p \cdot f)((p \cdot x) := (p \cdot y))$
unfolding *fun-upd-def*
by *simp*

lemma *comp-eqvt* [*eqvt*]:
 shows $p \cdot (f \circ g) = (p \cdot f) \circ (p \cdot g)$
unfolding *comp-def*
by *simp*

6.3.4 Equivariance for product operations

lemma *fst-eqvt* [*eqvt*]:
 shows $p \cdot (\text{fst } x) = \text{fst } (p \cdot x)$
 by (*cases x*) *simp*

lemma *snd-eqvt* [*eqvt*]:
 shows $p \cdot (\text{snd } x) = \text{snd } (p \cdot x)$
 by (*cases x*) *simp*

lemma *split-eqvt* [*eqvt*]:
 shows $p \cdot (\text{case-prod } P x) = \text{case-prod } (p \cdot P) (p \cdot x)$
 unfolding *split-def*
 by *simp*

6.3.5 Equivariance for list operations

lemma *append-eqvt* [*eqvt*]:
 shows $p \cdot (xs @ ys) = (p \cdot xs) @ (p \cdot ys)$
 by (*induct xs*) *auto*

lemma *rev-eqvt* [*eqvt*]:
 shows $p \cdot (\text{rev } xs) = \text{rev } (p \cdot xs)$
 by (*induct xs*) (*simp-all add: append-eqvt*)

lemma *map-eqvt* [*eqvt*]:
 shows $p \cdot (\text{map } f xs) = \text{map } (p \cdot f) (p \cdot xs)$
 by (*induct xs*) (*simp-all*)

lemma *removeAll-eqvt* [*eqvt*]:
 shows $p \cdot (\text{removeAll } x xs) = \text{removeAll } (p \cdot x) (p \cdot xs)$
 by (*induct xs*) (*auto*)

```

lemma filter-eqvt [eqvt]:
  shows  $p \cdot (\text{filter } f \text{ } xs) = \text{filter } (p \cdot f) (p \cdot xs)$ 
apply(induct xs)
apply(simp)
apply(simp only: filter.simps permute-list.simps if-eqvt)
apply(simp only: permute-fun-app-eq)
done

```

```

lemma distinct-eqvt [eqvt]:
  shows  $p \cdot (\text{distinct } xs) = \text{distinct } (p \cdot xs)$ 
apply(induct xs)
apply(simp add: permute-bool-def)
apply(simp add: conj-eqvt Not-eqvt mem-eqvt set-eqvt)
done

```

```

lemma length-eqvt [eqvt]:
  shows  $p \cdot (\text{length } xs) = \text{length } (p \cdot xs)$ 
by (induct xs) (simp-all add: permute-pure)

```

6.3.6 Equivariance for 'a option

```

lemma map-option-eqvt[eqvt]:
  shows  $p \cdot (\text{map-option } f \text{ } x) = \text{map-option } (p \cdot f) (p \cdot x)$ 
by (cases x) (simp-all)

```

6.3.7 Equivariance for 'a fset

context includes *fset.lifting* **begin**

```

lemma in-fset-eqvt [eqvt]:
  shows  $(p \cdot (x \in S)) = ((p \cdot x) \in (p \cdot S))$ 
by transfer simp

```

```

lemma union-fset-eqvt [eqvt]:
  shows  $(p \cdot (S \cup T)) = ((p \cdot S) \cup (p \cdot T))$ 
by (induct S) (simp-all)

```

```

lemma inter-fset-eqvt [eqvt]:
  shows  $(p \cdot (S \cap T)) = ((p \cdot S) \cap (p \cdot T))$ 
by transfer simp

```

```

lemma subset-fset-eqvt [eqvt]:
  shows  $(p \cdot (S \subseteq T)) = ((p \cdot S) \subseteq (p \cdot T))$ 
by transfer simp

```

```

lemma map-fset-eqvt [eqvt]:
  shows  $p \cdot (f \upharpoonright S) = (p \cdot f) \upharpoonright (p \cdot S)$ 
by transfer simp
end

```

6.3.8 Equivariance for ('a, 'b) finfun

lemma *finfun-update-eqv* [eqvt]:

shows $(p \cdot (\text{finfun-update } f \ a \ b)) = \text{finfun-update } (p \cdot f) \ (p \cdot a) \ (p \cdot b)$
by (*transfer*) (*simp*)

lemma *finfun-const-eqv* [eqvt]:

shows $(p \cdot (\text{finfun-const } b)) = \text{finfun-const } (p \cdot b)$
by (*transfer*) (*simp*)

lemma *finfun-apply-eqv* [eqvt]:

shows $(p \cdot (\text{finfun-apply } f \ b)) = \text{finfun-apply } (p \cdot f) \ (p \cdot b)$
by (*transfer*) (*simp*)

7 Supp, Freshness and Supports

context *pt*

begin

definition

supp :: 'a \Rightarrow atom set

where

$\text{supp } x = \{a. \text{infinite } \{b. (a \rightleftharpoons b) \cdot x \neq x\}\}$

definition

fresh :: atom \Rightarrow 'a \Rightarrow bool (- # - [55, 55] 55)

where

$a \# x \equiv a \notin \text{supp } x$

end

lemma *supp-conv-fresh*:

shows $\text{supp } x = \{a. \neg a \# x\}$
unfolding *fresh-def* **by** *simp*

lemma *swap-rel-trans*:

assumes *sort-of* $a = \text{sort-of } b$

assumes *sort-of* $b = \text{sort-of } c$

assumes $(a \rightleftharpoons c) \cdot x = x$

assumes $(b \rightleftharpoons c) \cdot x = x$

shows $(a \rightleftharpoons b) \cdot x = x$

proof (*cases*)

assume $a = b \vee c = b$

with *assms* **show** $(a \rightleftharpoons b) \cdot x = x$ **by** *auto*

next

assume *: $\neg (a = b \vee c = b)$

have $((a \rightleftharpoons c) + (b \rightleftharpoons c) + (a \rightleftharpoons c)) \cdot x = x$

using *assms* **by** *simp*

also have $(a \rightleftharpoons c) + (b \rightleftharpoons c) + (a \rightleftharpoons c) = (a \rightleftharpoons b)$

using *assms* * **by** (*simp add: swap-triple*)
finally show $(a \rightleftharpoons b) \cdot x = x$.
qed

lemma *swap-fresh-fresh*:

assumes $a: a \# x$
and $b: b \# x$
shows $(a \rightleftharpoons b) \cdot x = x$
proof (*cases*)
assume *asm: sort-of a = sort-of b*
have *finite* $\{c. (a \rightleftharpoons c) \cdot x \neq x\}$ *finite* $\{c. (b \rightleftharpoons c) \cdot x \neq x\}$
using *a b unfolding fresh-def supp-def by simp-all*
then have *finite* $(\{c. (a \rightleftharpoons c) \cdot x \neq x\} \cup \{c. (b \rightleftharpoons c) \cdot x \neq x\})$ **by** *simp*
then obtain *c*
where $(a \rightleftharpoons c) \cdot x = x$ $(b \rightleftharpoons c) \cdot x = x$ *sort-of c = sort-of b*
by (*rule obtain-atom*) (*auto*)
then show $(a \rightleftharpoons b) \cdot x = x$ **using** *asm* **by** (*rule-tac swap-rel-trans*) (*simp-all*)
next
assume *sort-of a \neq sort-of b*
then show $(a \rightleftharpoons b) \cdot x = x$ **by** *simp*
qed

7.1 supp and fresh are equivariant

lemma *supp-eqvt* [*eqvt*]:

shows $p \cdot (\text{supp } x) = \text{supp } (p \cdot x)$
unfolding *supp-def* **by** *simp*

lemma *fresh-eqvt* [*eqvt*]:

shows $p \cdot (a \# x) = (p \cdot a) \# (p \cdot x)$
unfolding *fresh-def* **by** *simp*

lemma *fresh-permute-iff*:

shows $(p \cdot a) \# (p \cdot x) \longleftrightarrow a \# x$
by (*simp only: fresh-eqvt[symmetric] permute-bool-def*)

lemma *fresh-permute-left*:

shows $a \# p \cdot x \longleftrightarrow - p \cdot a \# x$

proof

assume $a \# p \cdot x$

then have $- p \cdot a \# - p \cdot p \cdot x$ **by** (*simp only: fresh-permute-iff*)

then show $- p \cdot a \# x$ **by** *simp*

next

assume $- p \cdot a \# x$

then have $p \cdot - p \cdot a \# p \cdot x$ **by** (*simp only: fresh-permute-iff*)

then show $a \# p \cdot x$ **by** *simp*

qed

8 supports

definition

supports :: atom set \Rightarrow 'a::pt \Rightarrow bool (infixl supports 80)

where

S supports $x \equiv \forall a b. (a \notin S \wedge b \notin S \longrightarrow (a \rightleftharpoons b) \cdot x = x)$

lemma *supp-is-subset*:

fixes S :: atom set

and x :: 'a::pt

assumes $a1$: S supports x

and $a2$: finite S

shows $(\text{supp } x) \subseteq S$

proof (rule ccontr)

assume $\neg (\text{supp } x \subseteq S)$

then obtain a **where** $b1$: $a \in \text{supp } x$ **and** $b2$: $a \notin S$ **by** auto

from $a1$ $b2$ **have** $\forall b. b \notin S \longrightarrow (a \rightleftharpoons b) \cdot x = x$ **unfolding** *supports-def* **by** auto

then have $\{b. (a \rightleftharpoons b) \cdot x \neq x\} \subseteq S$ **by** auto

with $a2$ **have** finite $\{b. (a \rightleftharpoons b) \cdot x \neq x\}$ **by** (simp add: finite-subset)

then have $a \notin (\text{supp } x)$ **unfolding** *supp-def* **by** simp

with $b1$ **show** False **by** simp

qed

lemma *supports-finite*:

fixes S :: atom set

and x :: 'a::pt

assumes $a1$: S supports x

and $a2$: finite S

shows finite $(\text{supp } x)$

proof –

have $(\text{supp } x) \subseteq S$ **using** $a1$ $a2$ **by** (rule *supp-is-subset*)

then show finite $(\text{supp } x)$ **using** $a2$ **by** (simp add: finite-subset)

qed

lemma *supp-supports*:

fixes x :: 'a::pt

shows $(\text{supp } x)$ supports x

unfolding *supports-def*

proof (intro strip)

fix $a b$

assume $a \notin (\text{supp } x) \wedge b \notin (\text{supp } x)$

then have $a \not\# x$ **and** $b \not\# x$ **by** (simp-all add: fresh-def)

then show $(a \rightleftharpoons b) \cdot x = x$ **by** (simp add: swap-fresh-fresh)

qed

lemma *supports-fresh*:

fixes x :: 'a::pt

assumes $a1$: S supports x

```

and a2: finite S
and a3: a ∉ S
shows a # x
unfolding fresh-def
proof -
  have (supp x) ⊆ S using a1 a2 by (rule supp-is-subset)
  then show a ∉ (supp x) using a3 by auto
qed

```

```

lemma supp-is-least-supports:
  fixes S :: atom set
  and x :: 'a::pt
  assumes a1: S supports x
  and a2: finite S
  and a3: ⋀ S'. finite S' ⟹ (S' supports x) ⟹ S ⊆ S'
  shows (supp x) = S
proof (rule equalityI)
  show (supp x) ⊆ S using a1 a2 by (rule supp-is-subset)
  with a2 have fin: finite (supp x) by (rule rev-finite-subset)
  have (supp x) supports x by (rule supp-supports)
  with fin a3 show S ⊆ supp x by blast
qed

```

```

lemma subsetCI:
  shows (⋀ x. x ∈ A ⟹ x ∉ B ⟹ False) ⟹ A ⊆ B
  by auto

```

```

lemma finite-supp-unique:
  assumes a1: S supports x
  assumes a2: finite S
  assumes a3: ⋀ a b. [a ∈ S; b ∉ S; sort-of a = sort-of b] ⟹ (a ⇔ b) · x ≠ x
  shows (supp x) = S
  using a1 a2
proof (rule supp-is-least-supports)
  fix S'
  assume finite S' and S' supports x
  show S ⊆ S'
  proof (rule subsetCI)
    fix a
    assume a ∈ S and a ∉ S'
    have finite (S ∪ S')
      using ⟨finite S⟩ ⟨finite S'⟩ by simp
    then obtain b where b ∉ S ∪ S' and sort-of b = sort-of a
      by (rule obtain-atom)
    then have b ∉ S and b ∉ S' and sort-of a = sort-of b
      by simp-all
    then have (a ⇔ b) · x = x
      using ⟨a ∉ S'⟩ ⟨S' supports x⟩ by (simp add: supports-def)
  qed

```

```

moreover have  $(a \rightleftharpoons b) \cdot x \neq x$ 
  using  $\langle a \in S \rangle \langle b \notin S \rangle \langle \text{sort-of } a = \text{sort-of } b \rangle$ 
  by (rule a3)
  ultimately show False by simp
qed
qed

```

9 Support w.r.t. relations

This definition is used for unquotient types, where alpha-equivalence does not coincide with equality.

definition

```

supp-rel  $R$   $x = \{a. \text{infinite } \{b. \neg(R ((a \rightleftharpoons b) \cdot x) x)\}\}$ 

```

10 Finitely-supported types

```

class fs = pt +
  assumes finite-supp: finite (supp  $x$ )

```

lemma *pure-supp*:

```

fixes  $x::'a::\text{pure}$ 
shows  $\text{supp } x = \{\}$ 
unfolding supp-def by (simp add: permute-pure)

```

lemma *pure-fresh*:

```

fixes  $x::'a::\text{pure}$ 
shows  $a \# x$ 
unfolding fresh-def by (simp add: pure-supp)

```

instance *pure* < *fs*

```

by standard (simp add: pure-supp)

```

10.1 Type *atom* is finitely-supported.

lemma *supp-atom*:

```

shows  $\text{supp } a = \{a\}$ 
apply (rule finite-supp-unique)
apply (clarsimp simp add: supports-def)
apply simp
apply simp
done

```

lemma *fresh-atom*:

```

shows  $a \# b \longleftrightarrow a \neq b$ 
unfolding fresh-def supp-atom by simp

```

instance *atom* :: *fs*

```

by standard (simp add: supp-atom)

```


11 Type *perm* is finitely-supported.

lemma *perm-swap-eq*:

shows $(a \rightleftharpoons b) \cdot p = p \longleftrightarrow (p \cdot (a \rightleftharpoons b)) = (a \rightleftharpoons b)$

unfolding *permute-perm-def*

by (*metis add-diff-cancel minus-perm-def*)

lemma *supports-perm*:

shows $\{a. p \cdot a \neq a\}$ *supports* *p*

unfolding *supports-def*

unfolding *perm-swap-eq*

by (*simp add: swap-eqvt*)

lemma *finite-perm-lemma*:

shows *finite* $\{a::atom. p \cdot a \neq a\}$

using *finite-Rep-perm* [of *p*]

unfolding *permute-atom-def* .

lemma *supp-perm*:

shows $\text{supp } p = \{a. p \cdot a \neq a\}$

apply (*rule finite-supp-unique*)

apply (*rule supports-perm*)

apply (*rule finite-perm-lemma*)

apply (*simp add: perm-swap-eq swap-eqvt*)

apply (*auto simp: perm-eq-iff swap-atom*)

done

lemma *fresh-perm*:

shows $a \# p \longleftrightarrow p \cdot a = a$

unfolding *fresh-def*

by (*simp add: supp-perm*)

lemma *supp-swap*:

shows $\text{supp } (a \rightleftharpoons b) = (\text{if } a = b \vee \text{sort-of } a \neq \text{sort-of } b \text{ then } \{\} \text{ else } \{a, b\})$

by (*auto simp: supp-perm swap-atom*)

lemma *fresh-swap*:

shows $a \# (b \rightleftharpoons c) \longleftrightarrow (\text{sort-of } b \neq \text{sort-of } c) \vee b = c \vee (a \# b \wedge a \# c)$

by (*simp add: fresh-def supp-swap supp-atom*)

lemma *fresh-zero-perm*:

shows $a \# (0::perm)$

unfolding *fresh-perm* **by** *simp*

lemma *supp-zero-perm*:

shows $\text{supp } (0::perm) = \{\}$

unfolding *supp-perm* **by** *simp*

lemma *fresh-plus-perm*:

```

fixes p q::perm
assumes a # p a # q
shows a # (p + q)
using assms
unfolding fresh-def
by (auto simp: supp-perm)

```

```

lemma supp-plus-perm:
fixes p q::perm
shows  $\text{supp } (p + q) \subseteq \text{supp } p \cup \text{supp } q$ 
by (auto simp: supp-perm)

```

```

lemma fresh-minus-perm:
fixes p::perm
shows  $a \# (- p) \longleftrightarrow a \# p$ 
unfolding fresh-def
unfolding supp-perm
apply(simp)
apply(metis permute-minus-cancel)
done

```

```

lemma supp-minus-perm:
fixes p::perm
shows  $\text{supp } (- p) = \text{supp } p$ 
unfolding supp-conv-fresh
by (simp add: fresh-minus-perm)

```

```

lemma plus-perm-eq:
fixes p q::perm
assumes asm:  $\text{supp } p \cap \text{supp } q = \{\}$ 
shows  $p + q = q + p$ 
unfolding perm-eq-iff
proof
  fix a::atom
  show  $(p + q) \cdot a = (q + p) \cdot a$ 
  proof -
    { assume  $a \notin \text{supp } p \ a \notin \text{supp } q$ 
      then have  $(p + q) \cdot a = (q + p) \cdot a$ 
        by (simp add: supp-perm)
    }
  moreover
    { assume  $a \in \text{supp } p \ a \notin \text{supp } q$ 
      then have  $p \cdot a \in \text{supp } p$  by (simp add: supp-perm)
      then have  $p \cdot a \notin \text{supp } q$  using asm by auto
      with a have  $(p + q) \cdot a = (q + p) \cdot a$ 
        by (simp add: supp-perm)
    }
  moreover
    { assume  $a \notin \text{supp } p \ a \in \text{supp } q$ 

```

```

    then have  $q \cdot a \in \text{supp } q$  by (simp add: supp-perm)
    then have  $q \cdot a \notin \text{supp } p$  using asm by auto
    with a have  $(p + q) \cdot a = (q + p) \cdot a$ 
      by (simp add: supp-perm)
  }
  ultimately show  $(p + q) \cdot a = (q + p) \cdot a$ 
    using asm by blast
qed
qed

lemma supp-plus-perm-eq:
  fixes p q::perm
  assumes asm:  $\text{supp } p \cap \text{supp } q = \{\}$ 
  shows  $\text{supp } (p + q) = \text{supp } p \cup \text{supp } q$ 
proof -
  { fix a::atom
    assume  $a \in \text{supp } p$ 
    then have  $a \notin \text{supp } q$  using asm by auto
    then have  $a \in \text{supp } (p + q)$  using  $\langle a \in \text{supp } p \rangle$ 
      by (simp add: supp-perm)
  }
  moreover
  { fix a::atom
    assume  $a \in \text{supp } q$ 
    then have  $a \notin \text{supp } p$  using asm by auto
    then have  $a \in \text{supp } (q + p)$  using  $\langle a \in \text{supp } q \rangle$ 
      by (simp add: supp-perm)
    then have  $a \in \text{supp } (p + q)$  using asm plus-perm-eq
      by metis
  }
  ultimately have  $\text{supp } p \cup \text{supp } q \subseteq \text{supp } (p + q)$ 
    by blast
  then show  $\text{supp } (p + q) = \text{supp } p \cup \text{supp } q$  using supp-plus-perm
    by blast
qed

lemma perm-eq-iff2:
  fixes p q :: perm
  shows  $p = q \iff (\forall a::atom \in \text{supp } p \cup \text{supp } q. p \cdot a = q \cdot a)$ 
  unfolding perm-eq-iff
  apply(auto)
  apply(case-tac a # p ^ a # q)
  apply(simp add: fresh-perm)
  apply(simp add: fresh-def)
  done

instance perm :: fs
  by standard (simp add: supp-perm finite-perm-lemma)

```

12 Finite Support instances for other types

12.1 Type $'a \times 'b$ is finitely-supported.

lemma *supp-Pair*:

shows $\text{supp } (x, y) = \text{supp } x \cup \text{supp } y$

by (*simp add: supp-def Collect-imp-eq Collect-neg-eq*)

lemma *fresh-Pair*:

shows $a \# (x, y) \longleftrightarrow a \# x \wedge a \# y$

by (*simp add: fresh-def supp-Pair*)

lemma *supp-Unit*:

shows $\text{supp } () = \{\}$

by (*simp add: supp-def*)

lemma *fresh-Unit*:

shows $a \# ()$

by (*simp add: fresh-def supp-Unit*)

instance *prod* :: (fs, fs) *fs*

apply *standard*

apply (*case-tac x*)

apply (*simp add: supp-Pair finite-supp*)

done

12.2 Type $'a + 'b$ is finitely supported

lemma *supp-Inl*:

shows $\text{supp } (\text{Inl } x) = \text{supp } x$

by (*simp add: supp-def*)

lemma *supp-Inr*:

shows $\text{supp } (\text{Inr } x) = \text{supp } x$

by (*simp add: supp-def*)

lemma *fresh-Inl*:

shows $a \# \text{Inl } x \longleftrightarrow a \# x$

by (*simp add: fresh-def supp-Inl*)

lemma *fresh-Inr*:

shows $a \# \text{Inr } y \longleftrightarrow a \# y$

by (*simp add: fresh-def supp-Inr*)

instance *sum* :: (fs, fs) *fs*

apply *standard*

apply (*case-tac x*)

apply (*simp-all add: supp-Inl supp-Inr finite-supp*)

done

12.3 Type 'a option is finitely supported

lemma *supp-None*:

shows $\text{supp } \text{None} = \{\}$

by (*simp add: supp-def*)

lemma *supp-Some*:

shows $\text{supp } (\text{Some } x) = \text{supp } x$

by (*simp add: supp-def*)

lemma *fresh-None*:

shows $a \# \text{None}$

by (*simp add: fresh-def supp-None*)

lemma *fresh-Some*:

shows $a \# \text{Some } x \longleftrightarrow a \# x$

by (*simp add: fresh-def supp-Some*)

instance *option* :: (*fs*) *fs*

apply *standard*

apply (*induct-tac x*)

apply (*simp-all add: supp-None supp-Some finite-supp*)

done

12.3.1 Type 'a list is finitely supported

lemma *supp-Nil*:

shows $\text{supp } [] = \{\}$

by (*simp add: supp-def*)

lemma *fresh-Nil*:

shows $a \# []$

by (*simp add: fresh-def supp-Nil*)

lemma *supp-Cons*:

shows $\text{supp } (x \# xs) = \text{supp } x \cup \text{supp } xs$

by (*simp add: supp-def Collect-imp-eq Collect-neg-eq*)

lemma *fresh-Cons*:

shows $a \# (x \# xs) \longleftrightarrow a \# x \wedge a \# xs$

by (*simp add: fresh-def supp-Cons*)

lemma *supp-append*:

shows $\text{supp } (xs @ ys) = \text{supp } xs \cup \text{supp } ys$

by (*induct xs*) (*auto simp: supp-Nil supp-Cons*)

lemma *fresh-append*:

shows $a \# (xs @ ys) \longleftrightarrow a \# xs \wedge a \# ys$

by (*induct xs*) (*simp-all add: fresh-Nil fresh-Cons*)

lemma *supp-rev*:
shows $\text{supp } (\text{rev } xs) = \text{supp } xs$
by (*induct xs*) (*auto simp: supp-append supp-Cons supp-Nil*)

lemma *fresh-rev*:
shows $a \# \text{rev } xs \longleftrightarrow a \# xs$
by (*induct xs*) (*auto simp: fresh-append fresh-Cons fresh-Nil*)

lemma *supp-removeAll*:
fixes $x::\text{atom}$
shows $\text{supp } (\text{removeAll } x \ xs) = \text{supp } xs - \{x\}$
by (*induct xs*)
(auto simp: supp-Nil supp-Cons supp-atom)

lemma *supp-of-atom-list*:
fixes $as::\text{atom list}$
shows $\text{supp } as = \text{set } as$
by (*induct as*)
(simp-all add: supp-Nil supp-Cons supp-atom)

instance *list* :: $(fs) \ fs$
apply *standard*
apply (*induct-tac x*)
apply (*simp-all add: supp-Nil supp-Cons finite-supp*)
done

13 Support and Freshness for Applications

lemma *fresh-conv-MOST*:
shows $a \# x \longleftrightarrow (\text{MOST } b. (a \rightleftharpoons b) \cdot x = x)$
unfolding *fresh-def supp-def*
unfolding *MOST-iff-cofinite* **by** *simp*

lemma *fresh-fun-app*:
assumes $a \# f$ **and** $a \# x$
shows $a \# f \ x$
using *assms*
unfolding *fresh-conv-MOST*
unfolding *permute-fun-app-eq*
by (*elim MOST-rev-mp*) (*simp*)

lemma *supp-fun-app*:
shows $\text{supp } (f \ x) \subseteq (\text{supp } f) \cup (\text{supp } x)$
using *fresh-fun-app*
unfolding *fresh-def*
by *auto*

13.1 Equivariance Predicate *eqvt* and *eqvt-at*

definition

$$eqvt\ f \equiv \forall p. p \cdot f = f$$

lemma *eqvt-boolI*:

fixes *f::bool*

shows *eqvt f*

unfolding *eqvt-def* **by** (*simp add: permute-bool-def*)

equivariance of a function at a given argument

definition

$$eqvt-at\ f\ x \equiv \forall p. p \cdot (f\ x) = f\ (p \cdot x)$$

lemma *eqvtI*:

shows $(\bigwedge p. p \cdot f \equiv f) \implies eqvt\ f$

unfolding *eqvt-def*

by *simp*

lemma *eqvt-at-perm*:

assumes *eqvt-at f x*

shows *eqvt-at f (q · x)*

proof –

{ **fix** *p::perm*

have $p \cdot (f\ (q \cdot x)) = p \cdot q \cdot (f\ x)$

using *assms* **by** (*simp add: eqvt-at-def*)

also have $\dots = (p + q) \cdot (f\ x)$ **by** *simp*

also have $\dots = f\ ((p + q) \cdot x)$

using *assms* **by** (*simp only: eqvt-at-def*)

finally have $p \cdot (f\ (q \cdot x)) = f\ (p \cdot q \cdot x)$ **by** *simp* }

then show *eqvt-at f (q · x)* **unfolding** *eqvt-at-def*

by *simp*

qed

lemma *supp-fun-eqvt*:

assumes *a: eqvt f*

shows $supp\ f = \{\}$

using *a*

unfolding *eqvt-def*

unfolding *supp-def*

by *simp*

lemma *fresh-fun-eqvt*:

assumes *a: eqvt f*

shows $a \# f$

using *a*

unfolding *fresh-def*

by (*simp add: supp-fun-eqvt*)

lemma *fresh-fun-eqvt-app*:

```

assumes a: eqvt f
shows  $a \# x \implies a \# f x$ 
proof –
  from a have  $\text{supp } f = \{\}$  by (simp add: supp-fun-eqvt)
  then show  $a \# x \implies a \# f x$ 
    unfolding fresh-def
    using supp-fun-app by auto
qed

```

```

lemma supp-fun-app-eqvt:
  assumes a: eqvt f
  shows  $\text{supp } (f x) \subseteq \text{supp } x$ 
  using fresh-fun-eqvt-app[OF a]
  unfolding fresh-def
  by auto

```

```

lemma supp-eqvt-at:
  assumes asm: eqvt-at f x
  and fin: finite (supp x)
  shows  $\text{supp } (f x) \subseteq \text{supp } x$ 
apply(rule supp-is-subset)
unfolding supports-def
unfolding fresh-def[symmetric]
using asm
apply(simp add: eqvt-at-def)
apply(simp add: swap-fresh-fresh)
apply(rule fin)
done

```

```

lemma finite-supp-eqvt-at:
  assumes asm: eqvt-at f x
  and fin: finite (supp x)
  shows finite (supp (f x))
apply(rule finite-subset)
apply(rule supp-eqvt-at[OF asm fin])
apply(rule fin)
done

```

```

lemma fresh-eqvt-at:
  assumes asm: eqvt-at f x
  and fin: finite (supp x)
  and fresh:  $a \# x$ 
  shows  $a \# f x$ 
using fresh
unfolding fresh-def
using supp-eqvt-at[OF asm fin]
by auto

```

for handling of freshness of functions


```

simproc-setup fresh-fun-simproc (a ‡ (f::'a::pt =>'b::pt)) = ‹fn - => fn ctxt =>
fn ctrm =>
  let
    val - $ - $ f = Thm.term-of ctrm
  in
    case (Term.add-frees f [], Term.add-vars f []) of
      ([], []) => SOME(@{thm fresh-fun-eqvt[simplified eqvt-def, THEN Eq-TrueI]})
    | (x::-, []) =>
      let
        val argx = Free x
        val absf = absfree x f
        val cty-inst =
          [SOME (Thm.ctyp-of ctxt (fastype-of argx)), SOME (Thm.ctyp-of ctxt
(fastype-of f))]
        val ctrm-inst = [NONE, SOME (Thm.cterm-of ctxt absf), SOME (Thm.cterm-of
ctxt argx)]
        val thm = Thm.instantiate' cty-inst ctrm-inst @{thm fresh-fun-app}
      in
        SOME(thm RS @{thm Eq-TrueI})
      end
    | (-, -) => NONE
  end
›

```

13.2 helper functions for *nominal-functions*

lemma *THE-defaultI2*:

assumes $\exists!x. P x \wedge x. P x \implies Q x$

shows $Q (THE-default d P)$

by (*iprover intro: assms THE-defaultI'*)

lemma *the-default-*eqvt**:

assumes *unique*: $\exists!x. P x$

shows $(p \cdot (THE-default d P)) = (THE-default (p \cdot d) (p \cdot P))$

apply(*rule THE-default1-equality* [*symmetric*])

apply(*rule-tac p=-p in permute-boolE*)

apply(*simp add: ex1-*eqvt**)

apply(*rule unique*)

apply(*rule-tac p=-p in permute-boolE*)

apply(*rule subst[OF permute-fun-app-eq]*)

apply(*simp*)

apply(*rule THE-defaultI'[OF unique]*)

done

lemma *fundef-ex1-*eqvt**:

fixes $x::'a::pt$

assumes *f-def*: $f == (\lambda x::'a. THE-default (d x) (G x))$

assumes *eqvt*: *eqvt* *G*

assumes *ex1*: $\exists!y. G x y$

```

shows  $(p \cdot (f x)) = f (p \cdot x)$ 
apply(simp only: f-def)
apply(subst the-default-eqv)
apply(rule ex1)
apply(rule THE-default1-equality [symmetric])
apply(rule-tac p=-p in permute-boolE)
apply(perm-simp add: permute-minus-cancel)
using eqv[simplified eqv-def]
apply(simp)
apply(rule ex1)
apply(rule THE-defaultI2)
apply(rule-tac p=-p in permute-boolE)
apply(perm-simp add: permute-minus-cancel)
apply(rule ex1)
apply(perm-simp)
using eqv[simplified eqv-def]
apply(simp)
done

```

```

lemma fundef-ex1-eqv-at:
  fixes  $x::'a::pt$ 
  assumes f-def:  $f == (\lambda x::'a. \text{THE-default } (d x) (G x))$ 
  assumes eqv: eqv G
  assumes ex1:  $\exists!y. G x y$ 
  shows eqv-at f x
  unfolding eqv-at-def
  using assms
  by (auto intro: fundef-ex1-eqv)

```

```

lemma fundef-ex1-prop:
  fixes  $x::'a::pt$ 
  assumes f-def:  $f == (\lambda x::'a. \text{THE-default } (d x) (G x))$ 
  assumes P-all:  $\bigwedge x y. G x y \implies P x y$ 
  assumes ex1:  $\exists!y. G x y$ 
  shows  $P x (f x)$ 
  unfolding f-def
  using ex1
  apply(erule-tac ex1E)
  apply(rule THE-defaultI2)
  apply(blast)
  apply(rule P-all)
  apply(assumption)
  done

```

14 Support of Finite Sets of Finitely Supported Elements

support and freshness for atom sets

```

lemma supp-finite-atom-set:
  fixes  $S::atom\ set$ 
  assumes finite  $S$ 
  shows  $supp\ S = S$ 
  apply(rule finite-supp-unique)
  apply(simp add: supports-def)
  apply(simp add: swap-set-not-in)
  apply(rule assms)
  apply(simp add: swap-set-in)
done

lemma supp-cofinite-atom-set:
  fixes  $S::atom\ set$ 
  assumes finite  $(UNIV - S)$ 
  shows  $supp\ S = (UNIV - S)$ 
  apply(rule finite-supp-unique)
  apply(simp add: supports-def)
  apply(simp add: swap-set-both-in)
  apply(rule assms)
  apply(subst swap-commute)
  apply(simp add: swap-set-in)
done

lemma fresh-finite-atom-set:
  fixes  $S::atom\ set$ 
  assumes finite  $S$ 
  shows  $a \# S \longleftrightarrow a \notin S$ 
  unfolding fresh-def
  by (simp add: supp-finite-atom-set[OF assms])

lemma fresh-minus-atom-set:
  fixes  $S::atom\ set$ 
  assumes finite  $S$ 
  shows  $a \# S - T \longleftrightarrow (a \notin T \longrightarrow a \# S)$ 
  unfolding fresh-def
  by (auto simp: supp-finite-atom-set assms)

lemma Union-supports-set:
  shows  $(\bigcup x \in S. supp\ x)\ supports\ S$ 
proof -
  { fix  $a\ b$ 
    have  $\forall x \in S. (a \rightleftharpoons b) \cdot x = x \implies (a \rightleftharpoons b) \cdot S = S$ 
      unfolding permute-set-def by force
    }
  then show  $(\bigcup x \in S. supp\ x)\ supports\ S$ 
    unfolding supports-def
    by (simp add: fresh-def[symmetric] swap-fresh-fresh)
qed

```

```

lemma Union-of-finite-supp-sets:
  fixes  $S::('a::fs\ set)$ 
  assumes  $fin: finite\ S$ 
  shows  $finite\ (\bigcup_{x \in S}. supp\ x)$ 
  using  $fin$  by (induct) (auto simp: finite-supp)

lemma Union-included-in-supp:
  fixes  $S::('a::fs\ set)$ 
  assumes  $fin: finite\ S$ 
  shows  $(\bigcup_{x \in S}. supp\ x) \subseteq supp\ S$ 
proof –
  have  $eqvt: eqvt\ (\lambda S. \bigcup_{x \in S}. supp\ x)$ 
    unfolding eqvt-def by simp
  have  $(\bigcup_{x \in S}. supp\ x) = supp\ (\bigcup_{x \in S}. supp\ x)$ 
    by (rule supp-finite-atom-set[symmetric]) (rule Union-of-finite-supp-sets[OF
fin])
  also have  $\dots \subseteq supp\ S$  using eqvt
    by (rule supp-fun-app-eqvt)
  finally show  $(\bigcup_{x \in S}. supp\ x) \subseteq supp\ S$  .
qed

lemma supp-of-finite-sets:
  fixes  $S::('a::fs\ set)$ 
  assumes  $fin: finite\ S$ 
  shows  $(supp\ S) = (\bigcup_{x \in S}. supp\ x)$ 
apply(rule subset-antisym)
apply(rule supp-is-subset)
apply(rule Union-supports-set)
apply(rule Union-of-finite-supp-sets[OF fin])
apply(rule Union-included-in-supp[OF fin])
done

lemma finite-sets-supp:
  fixes  $S::('a::fs\ set)$ 
  assumes  $finite\ S$ 
  shows  $finite\ (supp\ S)$ 
using assms
by (simp only: supp-of-finite-sets Union-of-finite-supp-sets)

lemma supp-of-finite-union:
  fixes  $S\ T::('a::fs)\ set$ 
  assumes  $fin1: finite\ S$ 
  and  $fin2: finite\ T$ 
  shows  $supp\ (S \cup T) = supp\ S \cup supp\ T$ 
  using  $fin1\ fin2$ 
  by (simp add: supp-of-finite-sets)

lemma fresh-finite-union:
  fixes  $S\ T::('a::fs)\ set$ 

```

```

assumes fin1: finite S
and fin2: finite T
shows  $a \# (S \cup T) \longleftrightarrow a \# S \wedge a \# T$ 
unfolding fresh-def
by (simp add: supp-of-finite-union[OF fin1 fin2])

```

```

lemma supp-of-finite-insert:
fixes S::('a::fs) set
assumes fin: finite S
shows  $\text{supp } (\text{insert } x \ S) = \text{supp } x \cup \text{supp } S$ 
using fin
by (simp add: supp-of-finite-sets)

```

```

lemma fresh-finite-insert:
fixes S::('a::fs) set
assumes fin: finite S
shows  $a \# (\text{insert } x \ S) \longleftrightarrow a \# x \wedge a \# S$ 
using fin unfolding fresh-def
by (simp add: supp-of-finite-insert)

```

```

lemma supp-set-empty:
shows  $\text{supp } \{\} = \{\}$ 
unfolding supp-def
by (simp add: empty-eqvt)

```

```

lemma fresh-set-empty:
shows  $a \# \{\}$ 
by (simp add: fresh-def supp-set-empty)

```

```

lemma supp-set:
fixes xs :: ('a::fs) list
shows  $\text{supp } (\text{set } xs) = \text{supp } xs$ 
apply(induct xs)
apply(simp add: supp-set-empty supp-Nil)
apply(simp add: supp-Cons supp-of-finite-insert)
done

```

```

lemma fresh-set:
fixes xs :: ('a::fs) list
shows  $a \# (\text{set } xs) \longleftrightarrow a \# xs$ 
unfolding fresh-def
by (simp add: supp-set)

```

14.1 Type 'a multiset is finitely supported

```

lemma set-mset-eqvt [eqvt]:
shows  $p \cdot (\text{set-mset } M) = \text{set-mset } (p \cdot M)$ 
by (induct M) (simp-all add: insert-eqvt empty-eqvt)

```

```

lemma supp-set-mset:
  shows  $\text{supp } (\text{set-mset } M) \subseteq \text{supp } M$ 
  apply (rule supp-fun-app-eqvt)
  unfolding eqvt-def
  apply(perm-simp)
  apply(simp)
  done

lemma Union-finite-multiset:
  fixes  $M::'a::fs \text{ multiset}$ 
  shows  $\text{finite } (\bigcup \{\text{supp } x \mid x. x \in\# M\})$ 
  proof -
    have  $\text{finite } (\bigcup (\text{supp } ` \{x. x \in\# M\}))$ 
      by (induct M) (simp-all add: Collect-imp-eq Collect-neg-eq finite-supp)
    then show  $\text{finite } (\bigcup \{\text{supp } x \mid x. x \in\# M\})$ 
      by (simp only: image-Collect)
  qed

lemma Union-supports-multiset:
  shows  $\bigcup \{\text{supp } x \mid x. x \in\# M\} \text{ supports } M$ 
  proof -
    have  $sw: \bigwedge a b. ((\bigwedge x. x \in\# M \implies (a \rightleftharpoons b) \cdot x = x) \implies (a \rightleftharpoons b) \cdot M = M)$ 
      unfolding permute-multiset-def by (induct M) simp-all
    have  $(\bigcup_{x \in \text{set-mset } M}. \text{supp } x) \text{ supports } M$ 
      by (auto intro!: sw swap-fresh-fresh simp add: fresh-def supports-def)
    also have  $(\bigcup_{x \in \text{set-mset } M}. \text{supp } x) = (\bigcup \{\text{supp } x \mid x. x \in\# M\})$ 
      by auto
    finally show  $(\bigcup \{\text{supp } x \mid x. x \in\# M\}) \text{ supports } M$  .
  qed

lemma Union-included-multiset:
  fixes  $M::'a::fs \text{ multiset}$ 
  shows  $(\bigcup \{\text{supp } x \mid x. x \in\# M\}) \subseteq \text{supp } M$ 
  proof -
    have  $(\bigcup \{\text{supp } x \mid x. x \in\# M\}) = (\bigcup_{x \in \text{set-mset } M}. \text{supp } x)$  by auto
    also have  $\dots = \text{supp } (\text{set-mset } M)$ 
      by (simp add: supp-of-finite-sets)
    also have  $\dots \subseteq \text{supp } M$  by (rule supp-set-mset)
    finally show  $(\bigcup \{\text{supp } x \mid x. x \in\# M\}) \subseteq \text{supp } M$  .
  qed

lemma supp-of-multisets:
  fixes  $M::'a::fs \text{ multiset}$ 
  shows  $(\text{supp } M) = (\bigcup \{\text{supp } x \mid x. x \in\# M\})$ 
  apply(rule subset-antisym)
  apply(rule supp-is-subset)
  apply(rule Union-supports-multiset)
  apply(rule Union-finite-multiset)
  apply(rule Union-included-multiset)

```

done

lemma *multisets-supp-finite*:
 fixes $M::('a::fs\ multiset)$
 shows *finite (supp M)*
by (*simp only: supp-of-multisets Union-finite-multiset*)

lemma *supp-of-multiset-union*:
 fixes $M\ N::('a::fs)\ multiset$
 shows $supp\ (M + N) = supp\ M \cup supp\ N$
 by (*auto simp: supp-of-multisets*)

lemma *supp-empty-mset* [*simp*]:
 shows $supp\ \{\#\} = \{\}$
 unfolding *supp-def*
 by *simp*

instance *multiset* :: (*fs*) *fs*
 by *standard (rule multisets-supp-finite)*

14.2 Type 'a fset is finitely supported

lemma *supp-fset* [*simp*]:
 shows $supp\ (fset\ S) = supp\ S$
 unfolding *supp-def*
 by (*simp add: fset-eqvt fset-cong*)

lemma *supp-empty-fset* [*simp*]:
 shows $supp\ \{\|\} = \{\}$
 unfolding *supp-def*
 by *simp*

lemma *fresh-empty-fset*:
 shows $a \# \{\|\}$
unfolding *fresh-def*
by (*simp*)

lemma *supp-finsert* [*simp*]:
 fixes $x::'a::fs$
 and $S::'a\ fset$
 shows $supp\ (finsert\ x\ S) = supp\ x \cup supp\ S$
 apply(*subst supp-fset[symmetric]*)
 apply(*simp add: supp-of-finite-insert*)
 done

lemma *fresh-finsert*:
 fixes $x::'a::fs$
 and $S::'a\ fset$
 shows $a \# finsert\ x\ S \longleftrightarrow a \# x \wedge a \# S$

unfolding *fresh-def*
by *simp*

lemma *fset-finite-supp*:
fixes $S :: 'a::fs$ *fset*
shows *finite (supp S)*
by (*induct S*) (*simp-all add: finite-supp*)

lemma *supp-union-fset*:
fixes $S T :: 'a::fs$ *fset*
shows $\text{supp } (S \mid\cup\mid T) = \text{supp } S \cup \text{supp } T$
by (*induct S*) (*auto*)

lemma *fresh-union-fset*:
fixes $S T :: 'a::fs$ *fset*
shows $a \# S \mid\cup\mid T \longleftrightarrow a \# S \wedge a \# T$
unfolding *fresh-def*
by (*simp add: supp-union-fset*)

instance *fset* :: (*fs*) *fs*
by *standard (rule fset-finite-supp)*

14.3 Type $('a, 'b)$ *finfun* is finitely supported

lemma *fresh-finfun-const*:
shows $a \# (\text{finfun-const } b) \longleftrightarrow a \# b$
by (*simp add: fresh-def supp-def*)

lemma *fresh-finfun-update*:
shows $\llbracket a \# f; a \# x; a \# y \rrbracket \Longrightarrow a \# \text{finfun-update } f x y$
unfolding *fresh-conv-MOST*
unfolding *finfun-update-eqt*
by (*elim MOST-rev-mp*) (*simp*)

lemma *supp-finfun-const*:
shows $\text{supp } (\text{finfun-const } b) = \text{supp}(b)$
by (*simp add: supp-def*)

lemma *supp-finfun-update*:
shows $\text{supp } (\text{finfun-update } f x y) \subseteq \text{supp}(f, x, y)$
using *fresh-finfun-update*
by (*auto simp: fresh-def supp-Pair*)

instance *finfun* :: (*fs*, *fs*) *fs*
apply *standard*
apply (*induct-tac x rule: finfun-weak-induct*)
apply (*simp add: supp-finfun-const finite-supp*)
apply (*rule finite-subset*)
apply (*rule supp-finfun-update*)


```

apply(simp add: supp-Pair finite-supp)
done

```

15 Freshness and Fresh-Star

```

lemma fresh-Unit-elim:
  shows (a # ()  $\implies$  PROP C)  $\equiv$  PROP C
  by (simp add: fresh-Unit)

```

```

lemma fresh-Pair-elim:
  shows (a # (x, y)  $\implies$  PROP C)  $\equiv$  (a # x  $\implies$  a # y  $\implies$  PROP C)
  by rule (simp-all add: fresh-Pair)

```

```

lemma [simp]:
  shows a # x1  $\implies$  a # x2  $\implies$  a # (x1, x2)
  by (simp add: fresh-Pair)

```

```

lemma fresh-PairD:
  shows a # (x, y)  $\implies$  a # x
  and a # (x, y)  $\implies$  a # y
  by (simp-all add: fresh-Pair)

```

```

declaration ⟨fn - =>
  let
    val mksimps-pairs = (@{const-name Nominal2-Base.fresh}, @{thms fresh-PairD})
  :: mksimps-pairs
  in
    Simplifier.map-ss (fn ss => Simplifier.set-mksimps (mksimps mksimps-pairs) ss)
  end
  ⟩

```

The fresh-star generalisation of fresh is used in strong induction principles.

```

definition
  fresh-star :: atom set  $\implies$  'a::pt  $\implies$  bool (- #* - [80,80] 80)
where
  as #* x  $\equiv$   $\forall a \in as. a \# x$ 

```

```

lemma fresh-star-supp-conv:
  shows supp x #* y  $\implies$  supp y #* x
  by (auto simp: fresh-star-def fresh-def)

```

```

lemma fresh-star-perm-set-conv:
  fixes p::perm
  assumes fresh: as #* p
  and fin: finite as
  shows supp p #* as

```

apply(*rule fresh-star-supp-conv*)
apply(*simp add: supp-finite-atom-set fin fresh*)
done

lemma *fresh-star-atom-set-conv*:
assumes *fresh: as #* bs*
and *fin: finite as finite bs*
shows *bs #* as*
using *fresh*
unfolding *fresh-star-def fresh-def*
by (*auto simp: supp-finite-atom-set fin*)

lemma *atom-fresh-star-disjoint*:
assumes *fin: finite bs*
shows *as #* bs \longleftrightarrow (as \cap bs = {})*

unfolding *fresh-star-def fresh-def*
by (*auto simp: supp-finite-atom-set fin*)

lemma *fresh-star-Pair*:
shows *as #* (x, y) = (as #* x \wedge as #* y)*
by (*auto simp: fresh-star-def fresh-Pair*)

lemma *fresh-star-list*:
shows *as #* (xs @ ys) \longleftrightarrow as #* xs \wedge as #* ys*
and *as #* (x # xs) \longleftrightarrow as #* x \wedge as #* xs*
and *as #* []*
by (*auto simp: fresh-star-def fresh-Nil fresh-Cons fresh-append*)

lemma *fresh-star-set*:
fixes *xs::('a::fs) list*
shows *as #* set xs \longleftrightarrow as #* xs*
unfolding *fresh-star-def*
by (*simp add: fresh-set*)

lemma *fresh-star-singleton*:
fixes *a::atom*
shows *as #* {a} \longleftrightarrow as #* a*
by (*simp add: fresh-star-def fresh-finite-insert fresh-set-empty*)

lemma *fresh-star-fset*:
fixes *xs::('a::fs) list*
shows *as #* fset S \longleftrightarrow as #* S*
by (*simp add: fresh-star-def fresh-def*)

lemma *fresh-star-Un*:
shows *(as \cup bs) #* x = (as #* x \wedge bs #* x)*
by (*auto simp: fresh-star-def*)

lemma *fresh-star-insert*:

shows $(\text{insert } a \text{ as}) \#* x = (a \# x \wedge \text{as} \#* x)$
by (*auto simp: fresh-star-def*)

lemma *fresh-star-Un-elim*:

$((\text{as} \cup \text{bs}) \#* x \Longrightarrow \text{PROP } C) \equiv (\text{as} \#* x \Longrightarrow \text{bs} \#* x \Longrightarrow \text{PROP } C)$
unfolding *fresh-star-def*
apply(*rule*)
apply(*erule meta-mp*)
apply(*auto*)
done

lemma *fresh-star-insert-elim*:

$(\text{insert } a \text{ as} \#* x \Longrightarrow \text{PROP } C) \equiv (a \# x \Longrightarrow \text{as} \#* x \Longrightarrow \text{PROP } C)$
unfolding *fresh-star-def*
by rule (*simp-all add: fresh-star-def*)

lemma *fresh-star-empty-elim*:

$(\{\} \#* x \Longrightarrow \text{PROP } C) \equiv \text{PROP } C$
by (*simp add: fresh-star-def*)

lemma *fresh-star-Unit-elim*:

shows $(a \#* ()) \Longrightarrow \text{PROP } C) \equiv \text{PROP } C$
by (*simp add: fresh-star-def fresh-Unit*)

lemma *fresh-star-Pair-elim*:

shows $(a \#* (x, y) \Longrightarrow \text{PROP } C) \equiv (a \#* x \Longrightarrow a \#* y \Longrightarrow \text{PROP } C)$
by (*rule, simp-all add: fresh-star-Pair*)

lemma *fresh-star-zero*:

shows $\text{as} \#* (0::\text{perm})$
unfolding *fresh-star-def*
by (*simp add: fresh-zero-perm*)

lemma *fresh-star-plus*:

fixes $p \ q::\text{perm}$
shows $\llbracket a \#* p; a \#* q \rrbracket \Longrightarrow a \#* (p + q)$
unfolding *fresh-star-def*
by (*simp add: fresh-plus-perm*)

lemma *fresh-star-permute-iff*:

shows $(p \cdot a) \#* (p \cdot x) \longleftrightarrow a \#* x$
unfolding *fresh-star-def*
by (*metis mem-permute-iff permute-minus-cancel(1) fresh-permute-iff*)

lemma *fresh-star-eqvt* [*eqvt*]:

shows $p \cdot (\text{as} \#* x) \longleftrightarrow (p \cdot \text{as}) \#* (p \cdot x)$
unfolding *fresh-star-def* **by** *simp*

16 Induction principle for permutations

lemma *smaller-supp*:

assumes $a: a \in \text{supp } p$

shows $\text{supp } ((p \cdot a \rightleftharpoons a) + p) \subseteq \text{supp } p$

proof –

have $\text{supp } ((p \cdot a \rightleftharpoons a) + p) \subseteq \text{supp } p$

unfolding *supp-perm* **by** (*auto simp: swap-atom*)

moreover

have $a \notin \text{supp } ((p \cdot a \rightleftharpoons a) + p)$ **by** (*simp add: supp-perm*)

then have $\text{supp } ((p \cdot a \rightleftharpoons a) + p) \neq \text{supp } p$ **using** a **by** *auto*

ultimately

show $\text{supp } ((p \cdot a \rightleftharpoons a) + p) \subseteq \text{supp } p$ **by** *auto*

qed

lemma *perm-struct-induct*[*consumes 1, case-names zero swap*]:

assumes $S: \text{supp } p \subseteq S$

and $\text{zero}: P \ 0$

and $\text{swap}: \bigwedge p \ a \ b. \llbracket P \ p; \text{supp } p \subseteq S; a \in S; b \in S; a \neq b; \text{sort-of } a = \text{sort-of } b \rrbracket$
 $\implies P \ ((a \rightleftharpoons b) + p)$

shows $P \ p$

proof –

have *finite* ($\text{supp } p$) **by** (*simp add: finite-supp*)

then show $P \ p$ **using** S

proof(*induct* $A \equiv \text{supp } p$ *arbitrary: p rule: finite-psubset-induct*)

case (*psubset* p)

then have *ih*: $\bigwedge q. \text{supp } q \subseteq \text{supp } p \implies P \ q$ **by** *auto*

have *as*: $\text{supp } p \subseteq S$ **by** *fact*

{ **assume** $\text{supp } p = \{\}$

then have $p = 0$ **by** (*simp add: supp-perm perm-eq-iff*)

then have $P \ p$ **using** *zero* **by** *simp*

}

moreover

{ **assume** $\text{supp } p \neq \{\}$

then obtain a **where** $a0: a \in \text{supp } p$ **by** *blast*

then have $a1: p \cdot a \in S$ $a \in S$ $\text{sort-of } (p \cdot a) = \text{sort-of } a$ $p \cdot a \neq a$

using *as* **by** (*auto simp: supp-atom supp-perm swap-atom*)

let $?q = (p \cdot a \rightleftharpoons a) + p$

have $a2: \text{supp } ?q \subseteq \text{supp } p$ **using** $a0$ *smaller-supp* **by** *simp*

then have $P \ ?q$ **using** *ih* **by** *simp*

moreover

have $\text{supp } ?q \subseteq S$ **using** *as* $a2$ **by** *simp*

ultimately have $P \ ((p \cdot a \rightleftharpoons a) + ?q)$ **using** *as* $a1$ *swap* **by** *simp*

moreover

have $p = (p \cdot a \rightleftharpoons a) + ?q$ **by** (*simp add: perm-eq-iff*)

ultimately have $P \ p$ **by** *simp*

}

ultimately show $P \ p$ **by** *blast*

qed
qed

lemma *perm-simple-struct-induct*[*case-names zero swap*]:
assumes *zero*: $P\ 0$
and *swap*: $\bigwedge p\ a\ b. \llbracket P\ p; a \neq b; \text{sort-of } a = \text{sort-of } b \rrbracket \implies P\ ((a \rightleftharpoons b) + p)$
shows $P\ p$
by (*rule-tac S=supp p in perm-struct-induct*)
(*auto intro: zero swap*)

lemma *perm-struct-induct2*[*consumes 1, case-names zero swap plus*]:
assumes *S*: $\text{supp } p \subseteq S$
assumes *zero*: $P\ 0$
assumes *swap*: $\bigwedge a\ b. \llbracket \text{sort-of } a = \text{sort-of } b; a \neq b; a \in S; b \in S \rrbracket \implies P\ (a \rightleftharpoons b)$
assumes *plus*: $\bigwedge p1\ p2. \llbracket P\ p1; P\ p2; \text{supp } p1 \subseteq S; \text{supp } p2 \subseteq S \rrbracket \implies P\ (p1 + p2)$
shows $P\ p$
using *S*
by (*induct p rule: perm-struct-induct*)
(*auto intro: zero plus swap simp add: supp-swap*)

lemma *perm-simple-struct-induct2*[*case-names zero swap plus*]:
assumes *zero*: $P\ 0$
assumes *swap*: $\bigwedge a\ b. \llbracket \text{sort-of } a = \text{sort-of } b; a \neq b \rrbracket \implies P\ (a \rightleftharpoons b)$
assumes *plus*: $\bigwedge p1\ p2. \llbracket P\ p1; P\ p2 \rrbracket \implies P\ (p1 + p2)$
shows $P\ p$
by (*rule-tac S=supp p in perm-struct-induct2*)
(*auto intro: zero swap plus*)

lemma *supp-perm-singleton*:
fixes *p*::*perm*
shows $\text{supp } p \subseteq \{b\} \longleftrightarrow p = 0$
proof –
{ **assume** $\text{supp } p \subseteq \{b\}$
then have $p = 0$
by (*induct p rule: perm-struct-induct*) (*simp-all*)
}
then show $\text{supp } p \subseteq \{b\} \longleftrightarrow p = 0$ **by** (*auto simp: supp-zero-perm*)
qed

lemma *supp-perm-pair*:
fixes *p*::*perm*
shows $\text{supp } p \subseteq \{a, b\} \longleftrightarrow p = 0 \vee p = (b \rightleftharpoons a)$
proof –
{ **assume** $\text{supp } p \subseteq \{a, b\}$
then have $p = 0 \vee p = (b \rightleftharpoons a)$
apply (*induct p rule: perm-struct-induct*)
apply (*auto simp: swap-cancel supp-zero-perm supp-swap*)
}

```

    apply (simp add: swap-commute)
  done
}
then show  $\text{supp } p \subseteq \{a, b\} \iff p = 0 \vee p = (b \rightleftharpoons a)$ 
  by (auto simp: supp-zero-perm supp-swap split: if-splits)
qed

```

```

lemma supp-perm-eq:
  assumes (supp x)  $\#^* p$ 
  shows  $p \cdot x = x$ 
proof -
  from assms have  $\text{supp } p \subseteq \{a. a \# x\}$ 
  unfolding supp-perm fresh-star-def fresh-def by auto
  then show  $p \cdot x = x$ 
  proof (induct p rule: perm-struct-induct)
    case zero
    show  $0 \cdot x = x$  by simp
  next
    case (swap p a b)
    then have  $a \# x \ b \# x \ p \cdot x = x$  by simp-all
    then show  $((a \rightleftharpoons b) + p) \cdot x = x$  by (simp add: swap-fresh-fresh)
  qed
qed

```

same lemma as above, but proved with a different induction principle

```

lemma supp-perm-eq-test:
  assumes (supp x)  $\#^* p$ 
  shows  $p \cdot x = x$ 
proof -
  from assms have  $\text{supp } p \subseteq \{a. a \# x\}$ 
  unfolding supp-perm fresh-star-def fresh-def by auto
  then show  $p \cdot x = x$ 
  proof (induct p rule: perm-struct-induct2)
    case zero
    show  $0 \cdot x = x$  by simp
  next
    case (swap a b)
    then have  $a \# x \ b \# x$  by simp-all
    then show  $(a \rightleftharpoons b) \cdot x = x$  by (simp add: swap-fresh-fresh)
  next
    case (plus p1 p2)
    have  $p1 \cdot x = x \ p2 \cdot x = x$  by fact+
    then show  $(p1 + p2) \cdot x = x$  by simp
  qed
qed

```

```

lemma perm-supp-eq:
  assumes  $a: (\text{supp } p) \#^* x$ 
  shows  $p \cdot x = x$ 

```

```

proof –
  from assms have  $\text{supp } p \subseteq \{a. a \# x\}$ 
    unfolding supp-perm fresh-star-def fresh-def by auto
  then show  $p \cdot x = x$ 
  proof (induct p rule: perm-struct-induct2)
    case zero
      show  $0 \cdot x = x$  by simp
    next
      case (swap a b)
        then have  $a \# x \ b \# x$  by simp-all
        then show  $(a \rightleftharpoons b) \cdot x = x$  by (simp add: swap-fresh-fresh)
      next
        case (plus p1 p2)
          have  $p1 \cdot x = x \ p2 \cdot x = x$  by fact+
          then show  $(p1 + p2) \cdot x = x$  by simp
        qed
      qed
  qed

```

```

lemma supp-perm-perm-eq:
  assumes  $a: \forall a \in \text{supp } x. p \cdot a = q \cdot a$ 
  shows  $p \cdot x = q \cdot x$ 
proof –
  from  $a$  have  $\forall a \in \text{supp } x. (-q + p) \cdot a = a$  by simp
  then have  $\forall a \in \text{supp } x. a \notin \text{supp } (-q + p)$ 
    unfolding supp-perm by simp
  then have  $\text{supp } x \#^* (-q + p)$ 
    unfolding fresh-star-def fresh-def by simp
  then have  $(-q + p) \cdot x = x$  by (simp only: supp-perm-eq)
  then show  $p \cdot x = q \cdot x$ 
    by (metis permute-minus-cancel permute-plus)
qed

```

disagreement set

```

definition
  dset :: perm  $\Rightarrow$  perm  $\Rightarrow$  atom set
where
   $dset \ p \ q = \{a::atom. p \cdot a \neq q \cdot a\}$ 

```

```

lemma ds-fresh:
  assumes  $dset \ p \ q \#^* x$ 
  shows  $p \cdot x = q \cdot x$ 
using assms
unfolding dset-def fresh-star-def fresh-def
by (auto intro: supp-perm-perm-eq)

```

```

lemma atom-set-perm-eq:
  assumes  $a: as \#^* p$ 
  shows  $p \cdot as = as$ 
proof –

```

```

from  $a$  have  $\text{supp } p \subseteq \{a. a \notin as\}$ 
  unfolding  $\text{supp-perm fresh-star-def fresh-def}$  by  $\text{auto}$ 
then show  $p \cdot as = as$ 
proof ( $\text{induct } p$   $\text{rule: perm-struct-induct}$ )
  case  $\text{zero}$ 
    show  $0 \cdot as = as$  by  $\text{simp}$ 
  next
    case ( $\text{swap } p a b$ )
      then have  $a \notin as \ b \notin as \ p \cdot as = as$  by  $\text{simp-all}$ 
      then show  $((a \rightleftharpoons b) + p) \cdot as = as$  by ( $\text{simp add: swap-set-not-in}$ )
  qed
qed

```

17 Avoiding of atom sets

For every set of atoms, there is another set of atoms avoiding a finitely supported c and there is a permutation which 'translates' between both sets.

lemma $\text{at-set-avoiding-aux}$:

```

fixes  $Xs::\text{atom set}$ 
and  $As::\text{atom set}$ 
assumes  $b: Xs \subseteq As$ 
and  $c: \text{finite } As$ 
shows  $\exists p. (p \cdot Xs) \cap As = \{\} \wedge (\text{supp } p) = (Xs \cup (p \cdot Xs))$ 
proof –
  from  $b \ c$  have  $\text{finite } Xs$  by ( $\text{rule finite-subset}$ )
  then show  $?thesis$  using  $b$ 
  proof ( $\text{induct rule: finite-subset-induct}$ )
    case  $\text{empty}$ 
      have  $0 \cdot \{\} \cap As = \{\}$  by  $\text{simp}$ 
      moreover
        have  $\text{supp } (0::\text{perm}) = \{\} \cup 0 \cdot \{\}$  by ( $\text{simp add: supp-zero-perm}$ )
        ultimately show  $?case$  by  $\text{blast}$ 
    next
      case ( $\text{insert } x \ Xs$ )
        then obtain  $p$  where
           $p1: (p \cdot Xs) \cap As = \{\}$  and
           $p2: \text{supp } p = (Xs \cup (p \cdot Xs))$  by  $\text{blast}$ 
        from  $\langle x \in As \rangle \ p1$  have  $x \notin p \cdot Xs$  by  $\text{fast}$ 
        with  $\langle x \notin Xs \rangle \ p2$  have  $x \notin \text{supp } p$  by  $\text{fast}$ 
        hence  $p x: p \cdot x = x$  unfolding  $\text{supp-perm}$  by  $\text{simp}$ 
        have  $\text{finite } (As \cup p \cdot Xs \cup \text{supp } p)$ 
          using  $\langle \text{finite } As \rangle \ \langle \text{finite } Xs \rangle$ 
          by ( $\text{simp add: permute-set-eq-image finite-supp}$ )
        then obtain  $y$  where  $y \notin (As \cup p \cdot Xs \cup \text{supp } p)$   $\text{sort-of } y = \text{sort-of } x$ 
          by ( $\text{rule obtain-atom}$ )
        hence  $y: y \notin As \ y \notin p \cdot Xs \ y \notin \text{supp } p$   $\text{sort-of } y = \text{sort-of } x$ 
          by  $\text{simp-all}$ 

```



```

hence  $py: p \cdot y = y \ x \neq y$  using  $\langle x \in As \rangle$ 
  by (auto simp: supp-perm)
let  $?q = (x \rightleftharpoons y) + p$ 
have  $q: ?q \cdot insert\ x\ Xs = insert\ y\ (p \cdot Xs)$ 
  unfolding insert-eqt
  using  $\langle p \cdot x = x \rangle \langle sort\ of\ y = sort\ of\ x \rangle$ 
  using  $\langle x \notin p \cdot Xs \rangle \langle y \notin p \cdot Xs \rangle$ 
  by (simp add: swap-atom swap-set-not-in)
have  $?q \cdot insert\ x\ Xs \cap As = \{\}$ 
  using  $\langle y \notin As \rangle \langle p \cdot Xs \cap As = \{\} \rangle$ 
  unfolding  $q$  by simp
moreover
have  $supp\ (x \rightleftharpoons y) \cap supp\ p = \{\}$  using  $px\ py \ \langle sort\ of\ y = sort\ of\ x \rangle$ 
  unfolding supp-swap by (simp add: supp-perm)
then have  $supp\ ?q = (supp\ (x \rightleftharpoons y) \cup supp\ p)$ 
  by (simp add: supp-plus-perm-eq)
then have  $supp\ ?q = insert\ x\ Xs \cup ?q \cdot insert\ x\ Xs$ 
  using  $p2 \ \langle sort\ of\ y = sort\ of\ x \rangle \langle x \neq y \rangle$  unfolding  $q$  supp-swap
  by auto
ultimately show  $?case$  by blast
qed
qed

```

```

lemma at-set-avoiding:
  assumes  $a: finite\ Xs$ 
  and  $b: finite\ (supp\ c)$ 
  obtains  $p::perm$  where  $(p \cdot Xs) \#* c$  and  $(supp\ p) = (Xs \cup (p \cdot Xs))$ 
  using  $a\ b$  at-set-avoiding-aux [where  $Xs=Xs$  and  $As=Xs \cup supp\ c$ ]
  unfolding fresh-star-def fresh-def by blast

```

```

lemma at-set-avoiding1:
  assumes  $finite\ xs$ 
  and  $finite\ (supp\ c)$ 
  shows  $\exists p. (p \cdot xs) \#* c$ 
using assms
apply(erule-tac c=c in at-set-avoiding)
apply(auto)
done

```

```

lemma at-set-avoiding2:
  assumes  $finite\ xs$ 
  and  $finite\ (supp\ c)$   $finite\ (supp\ x)$ 
  and  $xs \#* x$ 
  shows  $\exists p. (p \cdot xs) \#* c \wedge supp\ x \#* p$ 
using assms
apply(erule-tac c=(c, x) in at-set-avoiding)
apply(simp add: supp-Pair)
apply(rule-tac x=p in exI)
apply(simp add: fresh-star-Pair)

```

```

apply(rule fresh-star-supp-conv)
apply(auto simp: fresh-star-def)
done

```

```

lemma at-set-avoiding3:
  assumes finite xs
  and     finite (supp c) finite (supp x)
  and     xs  $\#^*$  x
  shows  $\exists p. (p \cdot xs) \#^* c \wedge \text{supp } x \#^* p \wedge \text{supp } p = xs \cup (p \cdot xs)$ 
using assms
apply(erule-tac c=(c, x) in at-set-avoiding)
apply(simp add: supp-Pair)
apply(rule-tac x=p in exI)
apply(simp add: fresh-star-Pair)
apply(rule fresh-star-supp-conv)
apply(auto simp: fresh-star-def)
done

```

```

lemma at-set-avoiding2-atom:
  assumes finite (supp c) finite (supp x)
  and     b: a  $\#$  x
  shows  $\exists p. (p \cdot a) \# c \wedge \text{supp } x \#^* p$ 
proof –
  have a: {a}  $\#^*$  x unfolding fresh-star-def by (simp add: b)
  obtain p where p1: (p · {a})  $\#^*$  c and p2: supp x  $\#^*$  p
    using at-set-avoiding2[of {a} c x] assms a by blast
  have c: (p · a)  $\#$  c using p1
    unfolding fresh-star-def Ball-def
    by(erule-tac x=p · a in allE) (simp add: permute-set-def)
  hence p · a  $\#$  c  $\wedge$  supp x  $\#^*$  p using p2 by blast
  then show  $\exists p. (p \cdot a) \# c \wedge \text{supp } x \#^* p$  by blast
qed

```

18 Renaming permutations

```

lemma set-renaming-perm:
  assumes b: finite bs
  shows  $\exists q. (\forall b \in bs. q \cdot b = p \cdot b) \wedge \text{supp } q \subseteq bs \cup (p \cdot bs)$ 
using b
proof (induct)
  case empty
  have  $(\forall b \in \{\}. 0 \cdot b = p \cdot b) \wedge \text{supp } (0::perm) \subseteq \{\} \cup p \cdot \{\}$ 
    by (simp add: permute-set-def supp-perm)
  then show  $\exists q. (\forall b \in \{\}. q \cdot b = p \cdot b) \wedge \text{supp } q \subseteq \{\} \cup p \cdot \{\}$  by blast
next
  case (insert a bs)
  then have  $\exists q. (\forall b \in bs. q \cdot b = p \cdot b) \wedge \text{supp } q \subseteq bs \cup p \cdot bs$  by simp
  then obtain q where *:  $\forall b \in bs. q \cdot b = p \cdot b$  and **:  $\text{supp } q \subseteq bs \cup p \cdot bs$ 
    by (metis empty-subsetI insert(3) supp-swap)

```

```

{ assume 1:  $q \cdot a = p \cdot a$ 
  have  $\forall b \in (\text{insert } a \text{ } bs). q \cdot b = p \cdot b$  using 1 * by simp
  moreover
  have  $\text{supp } q \subseteq \text{insert } a \text{ } bs \cup p \cdot \text{insert } a \text{ } bs$ 
    using ** by (auto simp: insert-eqt)
  ultimately
  have  $\exists q. (\forall b \in \text{insert } a \text{ } bs. q \cdot b = p \cdot b) \wedge \text{supp } q \subseteq \text{insert } a \text{ } bs \cup p \cdot \text{insert}$ 
 $a \text{ } bs$  by blast
}
moreover
{ assume 2:  $q \cdot a \neq p \cdot a$ 
  define  $q'$  where  $q' = ((q \cdot a) \rightleftharpoons (p \cdot a)) + q$ 
  have  $\forall b \in \text{insert } a \text{ } bs. q' \cdot b = p \cdot b$  using 2 *  $\langle a \notin bs \rangle$  unfolding  $q'$ -def
    by (auto simp: swap-atom)
  moreover
  { have  $\{q \cdot a, p \cdot a\} \subseteq \text{insert } a \text{ } bs \cup p \cdot \text{insert } a \text{ } bs$ 
    using **
    apply (auto simp: supp-perm insert-eqt)
    apply (subgoal-tac  $q \cdot a \in bs \cup p \cdot bs$ )
    apply (auto)[1]
    apply (subgoal-tac  $q \cdot a \in \{a. q \cdot a \neq a\}$ )
    apply (blast)
    apply (simp)
    done
  then have  $\text{supp } (q \cdot a \rightleftharpoons p \cdot a) \subseteq \text{insert } a \text{ } bs \cup p \cdot \text{insert } a \text{ } bs$ 
    unfolding supp-swap by auto
  moreover
  have  $\text{supp } q \subseteq \text{insert } a \text{ } bs \cup p \cdot \text{insert } a \text{ } bs$ 
    using ** by (auto simp: insert-eqt)
  ultimately
  have  $\text{supp } q' \subseteq \text{insert } a \text{ } bs \cup p \cdot \text{insert } a \text{ } bs$ 
    unfolding  $q'$ -def using supp-plus-perm by blast
  }
  ultimately
  have  $\exists q. (\forall b \in \text{insert } a \text{ } bs. q \cdot b = p \cdot b) \wedge \text{supp } q \subseteq \text{insert } a \text{ } bs \cup p \cdot \text{insert}$ 
 $a \text{ } bs$  by blast
}
ultimately show  $\exists q. (\forall b \in \text{insert } a \text{ } bs. q \cdot b = p \cdot b) \wedge \text{supp } q \subseteq \text{insert } a \text{ } bs$ 
 $\cup p \cdot \text{insert } a \text{ } bs$ 
  by blast
qed

```

lemma *set-renaming-perm2*:

shows $\exists q. (\forall b \in bs. q \cdot b = p \cdot b) \wedge \text{supp } q \subseteq bs \cup (p \cdot bs)$

proof –

have *finite* ($bs \cap \text{supp } p$) by (simp add: finite-supp)

then obtain q

where *: $\forall b \in bs \cap \text{supp } p. q \cdot b = p \cdot b$ and **: $\text{supp } q \subseteq (bs \cap \text{supp } p) \cup$
 $(p \cdot (bs \cap \text{supp } p))$

```

    using set-renaming-perm by blast
  from ** have supp q ⊆ bs ∪ (p · bs) by (auto simp: inter-eqvt)
  moreover
  have ∀ b ∈ bs - supp p. q · b = p · b
    apply(auto)
    apply(subgoal-tac b ∉ supp q)
    apply(simp add: fresh-def[symmetric])
    apply(simp add: fresh-perm)
    apply(clarify)
    apply(rotate-tac 2)
    apply(drule subsetD[OF **])
    apply(simp add: inter-eqvt supp-eqvt permute-self)
  done
  ultimately have (∀ b ∈ bs. q · b = p · b) ∧ supp q ⊆ bs ∪ (p · bs) using * by
  auto
  then show ∃ q. (∀ b ∈ bs. q · b = p · b) ∧ supp q ⊆ bs ∪ (p · bs) by blast
qed

lemma list-renaming-perm:
  shows ∃ q. (∀ b ∈ set bs. q · b = p · b) ∧ supp q ⊆ set bs ∪ (p · set bs)
  proof (induct bs)
    case (Cons a bs)
    then have ∃ q. (∀ b ∈ set bs. q · b = p · b) ∧ supp q ⊆ set bs ∪ p · (set bs) by
  simp
    then obtain q where *: ∀ b ∈ set bs. q · b = p · b and **: supp q ⊆ set bs ∪ p
    · (set bs)
    by (blast)
    { assume 1: a ∈ set bs
      have q · a = p · a using * 1 by (induct bs) (auto)
      then have ∀ b ∈ set (a # bs). q · b = p · b using * by simp
      moreover
      have supp q ⊆ set (a # bs) ∪ p · (set (a # bs)) using ** by (auto simp:
  insert-eqvt)
      ultimately
      have ∃ q. (∀ b ∈ set (a # bs). q · b = p · b) ∧ supp q ⊆ set (a # bs) ∪ p · (set
  (a # bs)) by blast
    }
    moreover
    { assume 2: a ∉ set bs
      define q' where q' = ((q · a) ⇐ (p · a)) + q
      have ∀ b ∈ set (a # bs). q' · b = p · b
      unfolding q'-def using 2 * ⟨a ∉ set bs⟩ by (auto simp: swap-atom)
      moreover
      { have {q · a, p · a} ⊆ set (a # bs) ∪ p · (set (a # bs))
        using **
        apply (auto simp: supp-perm insert-eqvt)
        apply (subgoal-tac q · a ∈ set bs ∪ p · set bs)
        apply(auto)[1]
        apply(subgoal-tac q · a ∈ {a. q · a ≠ a})
      }
    }
  }

```

```

    apply(blast)
    apply(simp)
    done
  then have  $\text{supp } (q \cdot a \Rightarrow p \cdot a) \subseteq \text{set } (a \# bs) \cup p \cdot \text{set } (a \# bs)$ 
    unfolding supp-swap by auto
  moreover
  have  $\text{supp } q \subseteq \text{set } (a \# bs) \cup p \cdot (\text{set } (a \# bs))$ 
    using ** by (auto simp: insert-eqvt)
  ultimately
  have  $\text{supp } q' \subseteq \text{set } (a \# bs) \cup p \cdot (\text{set } (a \# bs))$ 
    unfolding q'-def using supp-plus-perm by blast
}
ultimately
have  $\exists q. (\forall b \in \text{set } (a \# bs). q \cdot b = p \cdot b) \wedge \text{supp } q \subseteq \text{set } (a \# bs) \cup p \cdot$ 
 $(\text{set } (a \# bs))$  by blast
}
ultimately show  $\exists q. (\forall b \in \text{set } (a \# bs). q \cdot b = p \cdot b) \wedge \text{supp } q \subseteq \text{set } (a \#$ 
 $bs) \cup p \cdot (\text{set } (a \# bs))$ 
  by blast
next
case Nil
  have  $(\forall b \in \text{set } []. 0 \cdot b = p \cdot b) \wedge \text{supp } (0::\text{perm}) \subseteq \text{set } [] \cup p \cdot \text{set } []$ 
    by (simp add: supp-zero-perm)
  then show  $\exists q. (\forall b \in \text{set } []. q \cdot b = p \cdot b) \wedge \text{supp } q \subseteq \text{set } [] \cup p \cdot (\text{set } [])$  by
blast
qed

```

19 Concrete Atoms Types

Class *at-base* allows types containing multiple sorts of atoms. Class *at* only allows types with a single sort.

```

class at-base = pt +
  fixes atom :: 'a  $\Rightarrow$  atom
  assumes atom-eq-iff [simp]: atom a = atom b  $\longleftrightarrow$  a = b
  assumes atom-eqvt: p  $\cdot$  (atom a) = atom (p  $\cdot$  a)

```

```

declare atom-eqvt [eqvt]

```

```

class at = at-base +
  assumes sort-of-atom-eq [simp]: sort-of (atom a) = sort-of (atom b)

```

```

lemma sort-ineq [simp]:
  assumes sort-of (atom a)  $\neq$  sort-of (atom b)
  shows atom a  $\neq$  atom b
using assms by metis

```

```

lemma supp-at-base:
  fixes a::'a::at-base

```

shows $\text{supp } a = \{\text{atom } a\}$
by (*simp* *add*: *supp-atom* [*symmetric*] *supp-def* *atom-eqvt*)

lemma *fresh-at-base*:
shows $\text{sort-of } a \neq \text{sort-of } (\text{atom } b) \implies a \# b$
and $a \# b \longleftrightarrow a \neq \text{atom } b$
unfolding *fresh-def*
apply(*simp-all* *add*: *supp-at-base*)
apply(*metis*)
done

lemma *fresh-ineq-at-base* [*simp*]:
shows $a \neq \text{atom } b \implies a \# b$
by (*simp* *add*: *fresh-at-base*)

lemma *fresh-atom-at-base* [*simp*]:
fixes $b::'a::\text{at-base}$
shows $a \# \text{atom } b \longleftrightarrow a \# b$
by (*simp* *add*: *fresh-def* *supp-at-base* *supp-atom*)

lemma *fresh-star-atom-at-base*:
fixes $b::'a::\text{at-base}$
shows $as \#* \text{atom } b \longleftrightarrow as \#* b$
by (*simp* *add*: *fresh-star-def* *fresh-atom-at-base*)

lemma *if-fresh-at-base* [*simp*]:
shows $\text{atom } a \# x \implies P (\text{if } a = x \text{ then } t \text{ else } s) = P s$
and $\text{atom } a \# x \implies P (\text{if } x = a \text{ then } t \text{ else } s) = P s$
by (*simp-all* *add*: *fresh-at-base*)

simproc-setup *fresh-ineq* ($x \neq (y::'a::\text{at-base})$) = $\langle \text{fn } - \implies \text{fn } \text{ctxt} \implies \text{fn } \text{ctrm}$
 \implies
case *Thm.term-of* *ctrm* of **Const**- $\langle \text{Not for } \mathbf{Const}$ - $\langle \text{HOL.eq} - \text{for lhs rhs} \rangle \rangle \implies$
let
fun *first-is-neg* *lhs* *rhs* [] = *NONE*
| *first-is-neg* *lhs* *rhs* (*thm*::*thms*) =
(*case* *Thm.prop-of* *thm* of
- \$ **Const**- $\langle \text{Not for } \mathbf{Const}$ - $\langle \text{HOL.eq} - \text{for } l r \rangle \rangle \implies$
(*if* $l = \text{lhs}$ *andalso* $r = \text{rhs}$ *then* *SOME*(*thm*)
else *if* $r = \text{lhs}$ *andalso* $l = \text{rhs}$ *then* *SOME*(*thm* *RS* @{*thm not-sym*})
else *first-is-neg* *lhs* *rhs* *thms*)
| - \implies *first-is-neg* *lhs* *rhs* *thms*)

val *simp-thms* = @{*thms* *fresh-Pair* *fresh-at-base* *atom-eq-iff*}
val *prems* = *Simplifier.prems-of* *ctxt*
|> *filter* (*fn* *thm* \implies *case* *Thm.prop-of* *thm* of

```

- $ Const- ⟨fresh - for ⟨- $ a⟩ b⟩ =>
  (let
    val atms = a :: HOLogic.strip-tuple b
  in
    member (op =) atms lhs andalso member (op =) atms rhs
  end)
| - => false)
|> map (simplify (put-simpset HOL-basic-ss ctxt addsimps simp-thms))
|> map (HOLogic.conj-elim3 ctxt)
|> flat
in
  case first-is-neg lhs rhs prems of
    SOME(thm) => SOME(thm RS @ {thm Eq-TrueI})
  | NONE => NONE
  end
| - => NONE
>

```

instance *at-base* < *fs*
proof **qed** (*simp add: supp-at-base*)

lemma *at-base-infinite* [*simp*]:
 shows *infinite* (UNIV :: 'a::at-base set) (**is infinite** ?U)
proof
 obtain a :: 'a where True by auto
 assume finite ?U
 hence finite (atom ' ?U)
 by (rule finite-imageI)
 then obtain b where b: b ∉ atom ' ?U sort-of b = sort-of (atom a)
 by (rule obtain-atom)
 from b(2) have b = atom ((atom a ⇔ b) · a)
 unfolding atom-eqvt [symmetric]
 by (simp add: swap-atom)
 hence b ∈ atom ' ?U by simp
 with b(1) show False by simp
qed

lemma *swap-at-base-simps* [*simp*]:
 fixes x y::'a::at-base
 shows sort-of (atom x) = sort-of (atom y) ⇒ (atom x ⇔ atom y) · x = y
 and sort-of (atom x) = sort-of (atom y) ⇒ (atom x ⇔ atom y) · y = x
 and atom x ≠ a ⇒ atom x ≠ b ⇒ (a ⇔ b) · x = x
 unfolding atom-eq-iff [symmetric]
 unfolding atom-eqvt [symmetric]
 by *simp-all*

lemma *obtain-at-base*:
 assumes X: finite X

```

obtains  $a :: 'a :: \text{at-base}$  where  $\text{atom } a \notin X$ 
proof –
  have  $\text{inj } (\text{atom} :: 'a \Rightarrow \text{atom})$ 
    by (simp add: inj-on-def)
  with  $X$  have  $\text{finite } (\text{atom} - ' X :: 'a \text{ set})$ 
    by (rule finite-vimageI)
  with  $\text{at-base-infinite}$  have  $\text{atom} - ' X \neq (\text{UNIV} :: 'a \text{ set})$ 
    by auto
  then obtain  $a :: 'a$  where  $\text{atom } a \notin X$ 
    by auto
  thus ?thesis ..
qed

```

```

lemma obtain-fresh':
  assumes  $\text{fin: finite } (\text{supp } x)$ 
  obtains  $a :: 'a :: \text{at-base}$  where  $\text{atom } a \# x$ 
using obtain-at-base [where  $X = \text{supp } x$ ]
by (auto simp: fresh-def fin)

```

```

lemma obtain-fresh:
  fixes  $x :: 'b :: \text{fs}$ 
  obtains  $a :: 'a :: \text{at-base}$  where  $\text{atom } a \# x$ 
by (rule obtain-fresh') (auto simp: finite-supp)

```

```

lemma supp-finite-set-at-base:
  assumes  $a: \text{finite } S$ 
  shows  $\text{supp } S = \text{atom } ' S$ 
apply (simp add: supp-of-finite-sets [OF  $a$ ])
apply (simp add: supp-at-base)
apply (auto)
done

```

```

lemma fresh-finite-set-at-base:
  fixes  $a :: 'a :: \text{at-base}$ 
  assumes  $a: \text{finite } S$ 
  shows  $\text{atom } a \# S \longleftrightarrow a \notin S$ 
unfolding fresh-def
apply (simp add: supp-finite-set-at-base [OF  $a$ ])
apply (subst inj-image-mem-iff)
apply (simp add: inj-on-def)
apply (simp)
done

```

```

lemma fresh-at-base-permute-iff [simp]:
  fixes  $a :: 'a :: \text{at-base}$ 
  shows  $\text{atom } (p \cdot a) \# p \cdot x \longleftrightarrow \text{atom } a \# x$ 
unfolding atom-eqvt [symmetric]

```


by (*simp only: fresh-permute-iff*)

lemma *fresh-at-base-permI*:

shows $\text{atom } a \# p \implies p \cdot a = a$

by (*simp add: fresh-def supp-perm*)

20 Infrastructure for concrete atom types

definition

flip :: $'a::\text{at-base} \Rightarrow 'a \Rightarrow \text{perm } ('(- \leftrightarrow -)')$

where

$(a \leftrightarrow b) = (\text{atom } a \rightleftharpoons \text{atom } b)$

lemma *flip-fresh-fresh*:

assumes $\text{atom } a \# x \text{ atom } b \# x$

shows $(a \leftrightarrow b) \cdot x = x$

using *assms*

by (*simp add: flip-def swap-fresh-fresh*)

lemma *flip-self* [*simp*]: $(a \leftrightarrow a) = 0$

unfolding *flip-def* by (*rule swap-self*)

lemma *flip-commute*: $(a \leftrightarrow b) = (b \leftrightarrow a)$

unfolding *flip-def* by (*rule swap-commute*)

lemma *minus-flip* [*simp*]: $-(a \leftrightarrow b) = (a \leftrightarrow b)$

unfolding *flip-def* by (*rule minus-swap*)

lemma *add-flip-cancel*: $(a \leftrightarrow b) + (a \leftrightarrow b) = 0$

unfolding *flip-def* by (*rule swap-cancel*)

lemma *permute-flip-cancel* [*simp*]: $(a \leftrightarrow b) \cdot (a \leftrightarrow b) \cdot x = x$

unfolding *permute-plus* [*symmetric*] *add-flip-cancel* by *simp*

lemma *permute-flip-cancel2* [*simp*]: $(a \leftrightarrow b) \cdot (b \leftrightarrow a) \cdot x = x$

by (*simp add: flip-commute*)

lemma *flip-eqvt* [*eqvt*]:

shows $p \cdot (a \leftrightarrow b) = (p \cdot a \leftrightarrow p \cdot b)$

unfolding *flip-def*

by (*simp add: swap-eqvt atom-eqvt*)

lemma *flip-at-base-simps* [*simp*]:

shows $\text{sort-of } (\text{atom } a) = \text{sort-of } (\text{atom } b) \implies (a \leftrightarrow b) \cdot a = b$

and $\text{sort-of } (\text{atom } a) = \text{sort-of } (\text{atom } b) \implies (a \leftrightarrow b) \cdot b = a$

and $\llbracket a \neq c; b \neq c \rrbracket \implies (a \leftrightarrow b) \cdot c = c$

and $\text{sort-of } (\text{atom } a) \neq \text{sort-of } (\text{atom } b) \implies (a \leftrightarrow b) \cdot x = x$

unfolding *flip-def*

unfolding *atom-eq-iff* [*symmetric*]

unfolding *atom-eqv* [*symmetric*]
by *simp-all*

the following two lemmas do not hold for *at-base*, only for single sort atoms from *at*

lemma *flip-triple*:
fixes *a b c::'a::at*
assumes $a \neq b$ **and** $c \neq b$
shows $(a \leftrightarrow c) + (b \leftrightarrow c) + (a \leftrightarrow c) = (a \leftrightarrow b)$
unfolding *flip-def*
by (*rule swap-triple*) (*simp-all add: assms*)

lemma *permute-flip-at*:
fixes *a b c::'a::at*
shows $(a \leftrightarrow b) \cdot c = (\text{if } c = a \text{ then } b \text{ else if } c = b \text{ then } a \text{ else } c)$
unfolding *flip-def*
apply (*rule atom-eq-iff [THEN iffD1]*)
apply (*subst atom-eqv [symmetric]*)
apply (*simp add: swap-atom*)
done

lemma *flip-at-simps [simp]*:
fixes *a b::'a::at*
shows $(a \leftrightarrow b) \cdot a = b$
and $(a \leftrightarrow b) \cdot b = a$
unfolding *permute-flip-at* **by** *simp-all*

20.1 Syntax for coercing at-elements to the atom-type

syntax

-atom-constrain :: *logic* \Rightarrow *type* \Rightarrow *logic* (*-::-* [*4*, *0*] *?*)

translations

-atom-constrain a t \Rightarrow *CONST atom (-constrain a t)*

20.2 A lemma for proving instances of class *at*.

setup \langle *Sign.add-const-constraint* ($\@$ {*const-name permute*}, *NONE*) \rangle

setup \langle *Sign.add-const-constraint* ($\@$ {*const-name atom*}, *NONE*) \rangle

New atom types are defined as subtypes of *atom*.

lemma *exists-eq-simple-sort*:
shows $\exists a. a \in \{a. \text{sort-of } a = s\}$
by (*rule-tac x=Atom s 0 in exI, simp*)

lemma *exists-eq-sort*:
shows $\exists a. a \in \{a. \text{sort-of } a \in \text{range sort-fun}\}$
by (*rule-tac x=Atom (sort-fun x) y in exI, simp*)

lemma *at-base-class*:

fixes *sort-fun* :: 'b \Rightarrow *atom-sort*

fixes *Rep* :: 'a \Rightarrow *atom* **and** *Abs* :: *atom* \Rightarrow 'a

assumes *type*: *type-definition* *Rep* *Abs* {*a*. *sort-of* *a* \in *range* *sort-fun*}

assumes *atom-def*: $\bigwedge a$. *atom* *a* = *Rep* *a*

assumes *permute-def*: $\bigwedge p$ *a*. *p* \cdot *a* = *Abs* (*p* \cdot *Rep* *a*)

shows *OFCLASS*('a, *at-base-class*)

proof

interpret *type-definition* *Rep* *Abs* {*a*. *sort-of* *a* \in *range* *sort-fun*} **by** (*rule type*)

have *sort-of-Rep*: $\bigwedge a$. *sort-of* (*Rep* *a*) \in *range* *sort-fun* **using** *Rep* **by** *simp*

fix *a* *b* :: 'a **and** *p* *p1* *p2* :: *perm*

show *0* \cdot *a* = *a*

unfolding *permute-def* **by** (*simp add*: *Rep-inverse*)

show (*p1* + *p2*) \cdot *a* = *p1* \cdot *p2* \cdot *a*

unfolding *permute-def* **by** (*simp add*: *Abs-inverse sort-of-Rep*)

show *atom* *a* = *atom* *b* \longleftrightarrow *a* = *b*

unfolding *atom-def* **by** (*simp add*: *Rep-inject*)

show *p* \cdot *atom* *a* = *atom* (*p* \cdot *a*)

unfolding *permute-def atom-def* **by** (*simp add*: *Abs-inverse sort-of-Rep*)

qed

lemma *at-class*:

fixes *s* :: *atom-sort*

fixes *Rep* :: 'a \Rightarrow *atom* **and** *Abs* :: *atom* \Rightarrow 'a

assumes *type*: *type-definition* *Rep* *Abs* {*a*. *sort-of* *a* = *s*}

assumes *atom-def*: $\bigwedge a$. *atom* *a* = *Rep* *a*

assumes *permute-def*: $\bigwedge p$ *a*. *p* \cdot *a* = *Abs* (*p* \cdot *Rep* *a*)

shows *OFCLASS*('a, *at-class*)

proof

interpret *type-definition* *Rep* *Abs* {*a*. *sort-of* *a* = *s*} **by** (*rule type*)

have *sort-of-Rep*: $\bigwedge a$. *sort-of* (*Rep* *a*) = *s* **using** *Rep* **by** (*simp add*: *image-def*)

fix *a* *b* :: 'a **and** *p* *p1* *p2* :: *perm*

show *0* \cdot *a* = *a*

unfolding *permute-def* **by** (*simp add*: *Rep-inverse*)

show (*p1* + *p2*) \cdot *a* = *p1* \cdot *p2* \cdot *a*

unfolding *permute-def* **by** (*simp add*: *Abs-inverse sort-of-Rep*)

show *sort-of* (*atom* *a*) = *sort-of* (*atom* *b*)

unfolding *atom-def* **by** (*simp add*: *sort-of-Rep*)

show *atom* *a* = *atom* *b* \longleftrightarrow *a* = *b*

unfolding *atom-def* **by** (*simp add*: *Rep-inject*)

show *p* \cdot *atom* *a* = *atom* (*p* \cdot *a*)

unfolding *permute-def atom-def* **by** (*simp add*: *Abs-inverse sort-of-Rep*)

qed

lemma *at-class-sort*:

fixes *s* :: *atom-sort*

fixes *Rep* :: 'a \Rightarrow *atom* **and** *Abs* :: *atom* \Rightarrow 'a

```

fixes  $a::'a$ 
assumes  $type: type-definition Rep Abs \{a. sort-of a = s\}$ 
assumes  $atom-def: \bigwedge a. atom a = Rep a$ 
shows  $sort-of (atom a) = s$ 
using  $atom-def type$ 
unfolding  $type-definition-def$  by  $simp$ 

```

```

setup  $\langle Sign.add-const-constraint$ 
   $(@{\{const-name permute\}, SOME @\{typ perm \Rightarrow 'a::pt \Rightarrow 'a\}}\rangle$ 
setup  $\langle Sign.add-const-constraint$ 
   $(@{\{const-name atom\}, SOME @\{typ 'a::at-base \Rightarrow atom\}}\rangle$ 

```

21 Library functions for the nominal infrastructure

ML-file $\langle nominal-library.ML \rangle$

22 The freshness lemma according to Andy Pitts

lemma $freshness-lemma:$

```

fixes  $h :: 'a::at \Rightarrow 'b::pt$ 
assumes  $a: \exists a. atom a \# (h, h a)$ 
shows  $\exists x. \forall a. atom a \# h \longrightarrow h a = x$ 

```

proof –

```

from  $a$  obtain  $b$  where  $a1: atom b \# h$  and  $a2: atom b \# h b$ 

```

```

  by  $(auto simp: fresh-Pair)$ 

```

```

show  $\exists x. \forall a. atom a \# h \longrightarrow h a = x$ 

```

```

proof  $(intro exI allI impI)$ 

```

```

  fix  $a :: 'a$ 

```

```

  assume  $a3: atom a \# h$ 

```

```

  show  $h a = h b$ 

```

```

  proof  $(cases a = b)$ 

```

```

    assume  $a = b$ 

```

```

    thus  $h a = h b$  by  $simp$ 

```

```

  next

```

```

    assume  $a \neq b$ 

```

```

    hence  $atom a \# b$  by  $(simp add: fresh-at-base)$ 

```

```

    with  $a3$  have  $atom a \# h b$ 

```

```

      by  $(rule fresh-fun-app)$ 

```

```

    with  $a2$  have  $d1: (atom b \rightleftharpoons atom a) \cdot (h b) = (h b)$ 

```

```

      by  $(rule swap-fresh-fresh)$ 

```

```

    from  $a1 a3$  have  $d2: (atom b \rightleftharpoons atom a) \cdot h = h$ 

```

```

      by  $(rule swap-fresh-fresh)$ 

```

```

    from  $d1$  have  $h b = (atom b \rightleftharpoons atom a) \cdot (h b)$  by  $simp$ 

```

```

    also have  $\dots = ((atom b \rightleftharpoons atom a) \cdot h) ((atom b \rightleftharpoons atom a) \cdot b)$ 

```

```

      by  $(rule permute-fun-app-eq)$ 

```

```

    also have  $\dots = h a$ 

```

```

    using d2 by simp
    finally show h a = h b by simp
  qed
qed
qed

```

```

lemma freshness-lemma-unique:
  fixes h :: 'a::at ⇒ 'b::pt
  assumes a: ∃ a. atom a # (h, h a)
  shows ∃!x. ∀ a. atom a # h ⟶ h a = x
proof (rule ex-ex1I)
  from a show ∃ x. ∀ a. atom a # h ⟶ h a = x
    by (rule freshness-lemma)
next
  fix x y
  assume x: ∀ a. atom a # h ⟶ h a = x
  assume y: ∀ a. atom a # h ⟶ h a = y
  from a x y show x = y
    by (auto simp: fresh-Pair)
qed

```

packaging the freshness lemma into a function

```

definition
  Fresh :: ('a::at ⇒ 'b::pt) ⇒ 'b
where
  Fresh h = (THE x. ∀ a. atom a # h ⟶ h a = x)

```

```

lemma Fresh-apply:
  fixes h :: 'a::at ⇒ 'b::pt
  assumes a: ∃ a. atom a # (h, h a)
  assumes b: atom a # h
  shows Fresh h = h a
unfolding Fresh-def
proof (rule the-equality)
  show ∀ a'. atom a' # h ⟶ h a' = h a
  proof (intro strip)
    fix a':: 'a
    assume c: atom a' # h
    from a have ∃ x. ∀ a. atom a # h ⟶ h a = x by (rule freshness-lemma)
    with b c show h a' = h a by auto
  qed
next
  fix fr :: 'b
  assume ∃ a. atom a # h ⟶ h a = fr
  with b show fr = h a by auto
qed

```

```

lemma Fresh-apply':
  fixes h :: 'a::at ⇒ 'b::pt

```

```

assumes  $a$ : atom  $a$  #  $h$  atom  $a$  #  $h$   $a$ 
shows Fresh  $h = h$   $a$ 
apply (rule Fresh-apply)
apply (auto simp: fresh-Pair intro:  $a$ )
done

simproc-setup Fresh-simproc (Fresh ( $h$ ::' $a$ ::at  $\Rightarrow$  ' $b$ ::pt)) = <fn - => fn ctxt =>
fn ctrm =>
  let
    val - $  $h =$  Thm.term-of ctrm

    val atoms = Simplifier.premis-of ctxt
    |> map-filter (fn thm => case Thm.prop-of thm of
      - $ Const-<fresh - for Const-<atom - for atm> -> => SOME atm | - =>
NONE)
    |> distinct (op =)

    fun get-thm atm =
      let
        val goal1 = HOLogic.mk-Trueprop (mk-fresh (mk-atom atm)  $h$ )
        val goal2 = HOLogic.mk-Trueprop (mk-fresh (mk-atom atm) ( $h$  $ atm))

        val thm1 = Goal.prove ctxt [] [] goal1 (fn {context = ctxt', ...} =>
asm-simp-tac ctxt' 1)
        val thm2 = Goal.prove ctxt [] [] goal2 (fn {context = ctxt', ...} =>
asm-simp-tac ctxt' 1)
      in
        SOME (@{thm Fresh-apply'} OF [thm1, thm2] RS eq-reflection)
      end handle ERROR - => NONE
    in
      get-first get-thm atoms
    end
  >

```

lemma Fresh-eqvt:

```

fixes  $h$  :: ' $a$ ::at  $\Rightarrow$  ' $b$ ::pt
assumes  $a$ :  $\exists a$ . atom  $a$  # ( $h$ ,  $h$   $a$ )
shows  $p \cdot$  (Fresh  $h$ ) = Fresh ( $p \cdot h$ )
proof -
from  $a$  obtain  $a$ ::' $a$ ::at where  $fr$ : atom  $a$  #  $h$  atom  $a$  #  $h$   $a$ 
by (metis fresh-Pair)
then have  $fr$ - $p$ : atom ( $p \cdot a$ ) # ( $p \cdot h$ ) atom ( $p \cdot a$ ) # ( $p \cdot h$ ) ( $p \cdot a$ )
by (metis atom-eqvt fresh-permute-iff eqvt-apply)+
have  $p \cdot$  (Fresh  $h$ ) =  $p \cdot$  ( $h$   $a$ ) using  $fr$  by simp
also have ... = ( $p \cdot h$ ) ( $p \cdot a$ ) by simp
also have ... = Fresh ( $p \cdot h$ ) using  $fr$ - $p$  by simp
finally show  $p \cdot$  (Fresh  $h$ ) = Fresh ( $p \cdot h$ ) .
qed

```

lemma *Fresh-supports*:
fixes $h :: 'a::at \Rightarrow 'b::pt$
assumes $a: \exists a. \text{atom } a \# (h, h a)$
shows $(\text{supp } h) \text{ supports } (\text{Fresh } h)$
apply $(\text{simp add: supports-def fresh-def [symmetric]})$
apply $(\text{simp add: Fresh-eqvt [OF a] swap-fresh-fresh})$
done

notation *Fresh* (**binder** *FRESH* 10)

lemma *FRESH-f-iff*:
fixes $P :: 'a::at \Rightarrow 'b::pure$
fixes $f :: 'b \Rightarrow 'c::pure$
assumes $P: \text{finite } (\text{supp } P)$
shows $(\text{FRESH } x. f (P x)) = f (\text{FRESH } x. P x)$
proof –
obtain $a::'a$ **where** $\text{atom } a \# P$ **using** P **by** $(\text{rule obtain-fresh'})$
then show $(\text{FRESH } x. f (P x)) = f (\text{FRESH } x. P x)$
by $(\text{simp add: pure-fresh})$
qed

lemma *FRESH-binop-iff*:
fixes $P :: 'a::at \Rightarrow 'b::pure$
fixes $Q :: 'a::at \Rightarrow 'c::pure$
fixes $\text{binop} :: 'b \Rightarrow 'c \Rightarrow 'd::pure$
assumes $P: \text{finite } (\text{supp } P)$
and $Q: \text{finite } (\text{supp } Q)$
shows $(\text{FRESH } x. \text{binop } (P x) (Q x)) = \text{binop } (\text{FRESH } x. P x) (\text{FRESH } x. Q x)$
proof –
from assms **have** $\text{finite } (\text{supp } (P, Q))$ **by** $(\text{simp add: supp-Pair})$
then obtain $a::'a$ **where** $\text{atom } a \# (P, Q)$ **by** $(\text{rule obtain-fresh'})$
then show $?thesis$
by $(\text{simp add: pure-fresh})$
qed

lemma *FRESH-conj-iff*:
fixes $P Q :: 'a::at \Rightarrow \text{bool}$
assumes $P: \text{finite } (\text{supp } P)$ **and** $Q: \text{finite } (\text{supp } Q)$
shows $(\text{FRESH } x. P x \wedge Q x) \longleftrightarrow (\text{FRESH } x. P x) \wedge (\text{FRESH } x. Q x)$
using $P Q$ **by** $(\text{rule FRESH-binop-iff})$

lemma *FRESH-disj-iff*:
fixes $P Q :: 'a::at \Rightarrow \text{bool}$
assumes $P: \text{finite } (\text{supp } P)$ **and** $Q: \text{finite } (\text{supp } Q)$
shows $(\text{FRESH } x. P x \vee Q x) \longleftrightarrow (\text{FRESH } x. P x) \vee (\text{FRESH } x. Q x)$
using $P Q$ **by** $(\text{rule FRESH-binop-iff})$

23 Automation for creating concrete atom types

At the moment only single-sort concrete atoms are supported.

ML-file \langle *nominal-atoms.ML* \rangle

24 Automatic equivariance procedure for inductive definitions

ML-file \langle *nominal-eqvt.ML* \rangle

```
end
theory Nominal2-Abs
imports Nominal2-Base
        HOL-Library.Quotient-List
        HOL-Library.Quotient-Product
begin
```

25 Abstractions

```
fun
  alpha-set
where
  alpha-set[simp del]:
  alpha-set (bs, x) R f p (cs, y)  $\longleftrightarrow$ 
    f x - bs = f y - cs  $\wedge$ 
    (f x - bs)  $\#$ * p  $\wedge$ 
    R (p  $\cdot$  x) y  $\wedge$ 
    p  $\cdot$  bs = cs
```

```
fun
  alpha-res
where
  alpha-res[simp del]:
  alpha-res (bs, x) R f p (cs, y)  $\longleftrightarrow$ 
    f x - bs = f y - cs  $\wedge$ 
    (f x - bs)  $\#$ * p  $\wedge$ 
    R (p  $\cdot$  x) y
```

```
fun
  alpha-lst
where
  alpha-lst[simp del]:
  alpha-lst (bs, x) R f p (cs, y)  $\longleftrightarrow$ 
    f x - set bs = f y - set cs  $\wedge$ 
    (f x - set bs)  $\#$ * p  $\wedge$ 
    R (p  $\cdot$  x) y  $\wedge$ 
    p  $\cdot$  bs = cs
```


lemmas *alphas* = *alpha-set.simps alpha-res.simps alpha-lst.simps*

notation

alpha-set (- \approx_{set} - - - - [100, 100, 100, 100, 100] 100) **and**
alpha-res (- \approx_{res} - - - - [100, 100, 100, 100, 100] 100) **and**
alpha-lst (- \approx_{lst} - - - - [100, 100, 100, 100, 100] 100)

26 Mono

lemma [*mono*]:

shows $R1 \leq R2 \implies \text{alpha-set } bs \ R1 \leq \text{alpha-set } bs \ R2$
and $R1 \leq R2 \implies \text{alpha-res } bs \ R1 \leq \text{alpha-res } bs \ R2$
and $R1 \leq R2 \implies \text{alpha-lst } cs \ R1 \leq \text{alpha-lst } cs \ R2$
by (*case-tac* [!] *bs*, *case-tac* [!] *cs*)
(auto simp: le-fun-def le-bool-def alphas)

27 Equivariance

lemma *alpha-eqvt*[*eqvt*]:

shows $(bs, x) \approx_{set} R \ f \ q \ (cs, y) \implies (p \cdot bs, p \cdot x) \approx_{set} (p \cdot R) \ (p \cdot f) \ (p \cdot q)$
 $(p \cdot cs, p \cdot y)$
and $(bs, x) \approx_{res} R \ f \ q \ (cs, y) \implies (p \cdot bs, p \cdot x) \approx_{res} (p \cdot R) \ (p \cdot f) \ (p \cdot q)$
 $(p \cdot cs, p \cdot y)$
and $(ds, x) \approx_{lst} R \ f \ q \ (es, y) \implies (p \cdot ds, p \cdot x) \approx_{lst} (p \cdot R) \ (p \cdot f) \ (p \cdot q) \ (p$
 $\cdot es, p \cdot y)$
unfolding *alphas*
unfolding *permute-eqvt*[*symmetric*]
unfolding *set-eqvt*[*symmetric*]
unfolding *permute-fun-app-eq*[*symmetric*]
unfolding *Diff-eqvt*[*symmetric*]
unfolding *eq-eqvt*[*symmetric*]
unfolding *fresh-star-eqvt*[*symmetric*]
by (*auto simp only: permute-bool-def*)

28 Equivalence

lemma *alpha-reft*:

assumes *a*: $R \ x \ x$
shows $(bs, x) \approx_{set} R \ f \ 0 \ (bs, x)$
and $(bs, x) \approx_{res} R \ f \ 0 \ (bs, x)$
and $(cs, x) \approx_{lst} R \ f \ 0 \ (cs, x)$
using *a*
unfolding *alphas*
unfolding *fresh-star-def*
by (*simp-all add: fresh-zero-perm*)

lemma *alpha-sym*:

assumes $a: R (p \cdot x) y \implies R (-p \cdot y) x$
shows $(bs, x) \approx_{set} R f p (cs, y) \implies (cs, y) \approx_{set} R f (-p) (bs, x)$
and $(bs, x) \approx_{res} R f p (cs, y) \implies (cs, y) \approx_{res} R f (-p) (bs, x)$
and $(ds, x) \approx_{lst} R f p (es, y) \implies (es, y) \approx_{lst} R f (-p) (ds, x)$
unfolding *alphas fresh-star-def*
using a
by (*auto simp: fresh-minus-perm*)

lemma *alpha-trans:*

assumes $a: \llbracket R (p \cdot x) y; R (q \cdot y) z \rrbracket \implies R ((q + p) \cdot x) z$
shows $\llbracket (bs, x) \approx_{set} R f p (cs, y); (cs, y) \approx_{set} R f q (ds, z) \rrbracket \implies (bs, x) \approx_{set} R f (q + p) (ds, z)$
and $\llbracket (bs, x) \approx_{res} R f p (cs, y); (cs, y) \approx_{res} R f q (ds, z) \rrbracket \implies (bs, x) \approx_{res} R f (q + p) (ds, z)$
and $\llbracket (es, x) \approx_{lst} R f p (gs, y); (gs, y) \approx_{lst} R f q (hs, z) \rrbracket \implies (es, x) \approx_{lst} R f (q + p) (hs, z)$
using a
unfolding *alphas fresh-star-def*
by (*simp-all add: fresh-plus-perm*)

lemma *alpha-sym-eqvt:*

assumes $a: R (p \cdot x) y \implies R y (p \cdot x)$
and $b: p \cdot R = R$
shows $(bs, x) \approx_{set} R f p (cs, y) \implies (cs, y) \approx_{set} R f (-p) (bs, x)$
and $(bs, x) \approx_{res} R f p (cs, y) \implies (cs, y) \approx_{res} R f (-p) (bs, x)$
and $(ds, x) \approx_{lst} R f p (es, y) \implies (es, y) \approx_{lst} R f (-p) (ds, x)$
apply(*auto intro!: alpha-sym*)
apply(*drule-tac [!] a*)
apply(*rule-tac [!] p=p in permute-boolE*)
apply(*simp-all add: b permute-self*)
done

lemma *alpha-set-trans-eqvt:*

assumes $b: (cs, y) \approx_{set} R f q (ds, z)$
and $a: (bs, x) \approx_{set} R f p (cs, y)$
and $d: q \cdot R = R$
and $c: \llbracket R (p \cdot x) y; R y (-q \cdot z) \rrbracket \implies R (p \cdot x) (-q \cdot z)$
shows $(bs, x) \approx_{set} R f (q + p) (ds, z)$
apply(*rule alpha-trans(1)[OF - a b]*)
apply(*drule c*)
apply(*rule-tac p=q in permute-boolE*)
apply(*simp add: d permute-self*)
apply(*rotate-tac -1*)
apply(*drule-tac p=q in permute-boolI*)
apply(*simp add: d permute-self permute-eqvt[symmetric]*)
done

lemma *alpha-res-trans-eqvt:*

assumes $b: (cs, y) \approx_{res} R f q (ds, z)$

```

and    a: (bs, x)  $\approx_{res}$  R f p (cs, y)
and    d: q · R = R
and    c:  $\llbracket R (p \cdot x) y; R y (- q \cdot z) \rrbracket \implies R (p \cdot x) (- q \cdot z)$ 
shows (bs, x)  $\approx_{res}$  R f (q + p) (ds, z)
apply(rule alpha-trans(2)[OF - a b])
apply(drule c)
apply(rule-tac p=q in permute-boolE)
apply(simp add: d permute-self)
apply(rotate-tac -1)
apply(drule-tac p=q in permute-boolI)
apply(simp add: d permute-self permute-eqvt[symmetric])
done

```

```

lemma alpha-lst-trans-eqvt:
  assumes b: (cs, y)  $\approx_{lst}$  R f q (ds, z)
  and    a: (bs, x)  $\approx_{lst}$  R f p (cs, y)
  and    d: q · R = R
  and    c:  $\llbracket R (p \cdot x) y; R y (- q \cdot z) \rrbracket \implies R (p \cdot x) (- q \cdot z)$ 
  shows (bs, x)  $\approx_{lst}$  R f (q + p) (ds, z)
apply(rule alpha-trans(3)[OF - a b])
apply(drule c)
apply(rule-tac p=q in permute-boolE)
apply(simp add: d permute-self)
apply(rotate-tac -1)
apply(drule-tac p=q in permute-boolI)
apply(simp add: d permute-self permute-eqvt[symmetric])
done

```

lemmas alpha-trans-eqvt = alpha-set-trans-eqvt alpha-res-trans-eqvt alpha-lst-trans-eqvt

29 General Abstractions

```

fun
  alpha-abs-set
where
  [simp del]:
  alpha-abs-set (bs, x) (cs, y)  $\longleftrightarrow (\exists p. (bs, x) \approx_{set} ((=)) \text{supp } p (cs, y))$ 

```

```

fun
  alpha-abs-lst
where
  [simp del]:
  alpha-abs-lst (bs, x) (cs, y)  $\longleftrightarrow (\exists p. (bs, x) \approx_{lst} ((=)) \text{supp } p (cs, y))$ 

```

```

fun
  alpha-abs-res
where
  [simp del]:
  alpha-abs-res (bs, x) (cs, y)  $\longleftrightarrow (\exists p. (bs, x) \approx_{res} ((=)) \text{supp } p (cs, y))$ 

```

notation

alpha-abs-set (**infix** $\approx_{abs'-set}$ 50) **and**
alpha-abs- lst (**infix** $\approx_{abs'-lst}$ 50) **and**
alpha-abs-res (**infix** $\approx_{abs'-res}$ 50)

lemmas *alphas-abs = alpha-abs-set.simps alpha-abs-res.simps alpha-abs- lst .simps*

lemma *alphas-abs-refl*:

shows $(bs, x) \approx_{abs-set} (bs, x)$
and $(bs, x) \approx_{abs-res} (bs, x)$
and $(cs, x) \approx_{abs- lst } (cs, x)$
unfolding *alphas-abs*
unfolding *alphas*
unfolding *fresh-star-def*
by (*rule-tac* [!] $x=0$ **in** exI)
(simp-all add: fresh-zero-perm)

lemma *alphas-abs-sym*:

shows $(bs, x) \approx_{abs-set} (cs, y) \implies (cs, y) \approx_{abs-set} (bs, x)$
and $(bs, x) \approx_{abs-res} (cs, y) \implies (cs, y) \approx_{abs-res} (bs, x)$
and $(ds, x) \approx_{abs- lst } (es, y) \implies (es, y) \approx_{abs- lst } (ds, x)$
unfolding *alphas-abs*
unfolding *alphas*
unfolding *fresh-star-def*
by (*erule-tac* [!] exE , *rule-tac* [!] $x=-p$ **in** exI)
(auto simp: fresh-minus-perm)

lemma *alphas-abs-trans*:

shows $\llbracket (bs, x) \approx_{abs-set} (cs, y); (cs, y) \approx_{abs-set} (ds, z) \rrbracket \implies (bs, x) \approx_{abs-set} (ds, z)$
and $\llbracket (bs, x) \approx_{abs-res} (cs, y); (cs, y) \approx_{abs-res} (ds, z) \rrbracket \implies (bs, x) \approx_{abs-res} (ds, z)$
and $\llbracket (es, x) \approx_{abs- lst } (gs, y); (gs, y) \approx_{abs- lst } (hs, z) \rrbracket \implies (es, x) \approx_{abs- lst } (hs, z)$
unfolding *alphas-abs*
unfolding *alphas*
unfolding *fresh-star-def*
apply(*erule-tac* [!] exE , *erule-tac* [!] exE)
apply(*rule-tac* [!] $x=pa + p$ **in** exI)
by (*simp-all add: fresh-plus-perm*)

lemma *alphas-abs-eqvt*:

shows $(bs, x) \approx_{abs-set} (cs, y) \implies (p \cdot bs, p \cdot x) \approx_{abs-set} (p \cdot cs, p \cdot y)$
and $(bs, x) \approx_{abs-res} (cs, y) \implies (p \cdot bs, p \cdot x) \approx_{abs-res} (p \cdot cs, p \cdot y)$
and $(ds, x) \approx_{abs- lst } (es, y) \implies (p \cdot ds, p \cdot x) \approx_{abs- lst } (p \cdot es, p \cdot y)$
unfolding *alphas-abs*
unfolding *alphas*

unfolding *set-eqvt*[*symmetric*]
unfolding *supp-eqvt*[*symmetric*]
unfolding *Diff-eqvt*[*symmetric*]
apply(*erule-tac* [!] *exE*)
apply(*rule-tac* [!] *x=p · pa in exI*)
by (*auto simp only: fresh-star-permute-iff permute-eqvt*[*symmetric*])

30 Strengthening the equivalence

lemma *disjoint-right-eq*:

assumes *a*: $A \cup B1 = A \cup B2$
and *b*: $A \cap B1 = \{\} A \cap B2 = \{\}$
shows $B1 = B2$

using *a b*

by (*metis Int-Un-distrib2 Int-absorb2 Int-commute Un-upper2*)

lemma *supp-property-res*:

assumes *a*: $(as, x) \approx_{res} (=) supp\ p\ (as', x')$
shows $p \cdot (supp\ x \cap as) = supp\ x' \cap as'$

proof –

from *a* **have** $(supp\ x - as) \#* p$ **by** (*auto simp only: alphas*)

then have $*$: $p \cdot (supp\ x - as) = (supp\ x - as)$

by (*simp add: atom-set-perm-eq*)

have $(supp\ x' - as') \cup (supp\ x' \cap as') = supp\ x'$ **by** *auto*

also have $\dots = supp\ (p \cdot x)$ **using** *a* **by** (*simp add: alphas*)

also have $\dots = p \cdot (supp\ x)$ **by** (*simp add: supp-eqvt*)

also have $\dots = p \cdot ((supp\ x - as) \cup (supp\ x \cap as))$ **by** *auto*

also have $\dots = (p \cdot (supp\ x - as)) \cup (p \cdot (supp\ x \cap as))$ **by** (*simp add: union-eqvt*)

also have $\dots = (supp\ x - as) \cup (p \cdot (supp\ x \cap as))$ **using** $*$ **by** *simp*

also have $\dots = (supp\ x' - as') \cup (p \cdot (supp\ x \cap as))$ **using** *a* **by** (*simp add: alphas*)

finally have $(supp\ x' - as') \cup (supp\ x' \cap as') = (supp\ x' - as') \cup (p \cdot (supp\ x \cap as))$.

moreover

have $(supp\ x' - as') \cap (supp\ x' \cap as') = \{\}$ **by** *auto*

moreover

have $(supp\ x - as) \cap (supp\ x \cap as) = \{\}$ **by** *auto*

then have $p \cdot ((supp\ x - as) \cap (supp\ x \cap as) = \{\})$ **by** (*simp add: permute-bool-def*)

then have $(p \cdot (supp\ x - as)) \cap (p \cdot (supp\ x \cap as)) = \{\}$ **by** (*perm-simp*) (*simp*)

then have $(supp\ x - as) \cap (p \cdot (supp\ x \cap as)) = \{\}$ **using** $*$ **by** *simp*

then have $(supp\ x' - as') \cap (p \cdot (supp\ x \cap as)) = \{\}$ **using** *a* **by** (*simp add: alphas*)

ultimately show $p \cdot (supp\ x \cap as) = supp\ x' \cap as'$

by (*auto dest: disjoint-right-eq*)

qed

lemma *alpha-abs-res-stronger1-aux*:

assumes $asm: (as, x) \approx_{res} (=) supp\ p' (as', x')$
shows $\exists p. (as, x) \approx_{res} (=) supp\ p (as', x') \wedge supp\ p \subseteq (supp\ x \cap as) \cup (supp\ x' \cap as')$
proof –
from asm **have** $0: (supp\ x - as) \#^* p'$ **by** $(auto\ simp\ only: alphas)$
then have $\#:$ $p' \cdot (supp\ x - as) = (supp\ x - as)$
by $(simp\ add: atom-set-perm-eq)$
obtain p **where** $*$: $\forall b \in supp\ x. p \cdot b = p' \cdot b$ **and** $**:$ $supp\ p \subseteq supp\ x \cup p' \cdot supp\ x$
using $set-renaming-perm2$ **by** $blast$
from $*$ **have** $a:$ $p \cdot x = p' \cdot x$ **using** $supp-perm-perm-eq$ **by** $auto$
from 0 **have** $1:$ $(supp\ x - as) \#^* p$ **using** $*$
by $(auto\ simp: fresh-star-def\ fresh-perm)$
then have $2:$ $(supp\ x - as) \cap supp\ p = \{\}$
by $(auto\ simp: fresh-star-def\ fresh-def)$
have $b:$ $supp\ x = (supp\ x - as) \cup (supp\ x \cap as)$ **by** $auto$
have $supp\ p \subseteq supp\ x \cup p' \cdot supp\ x$ **using** $**$ **by** $simp$
also have $\dots = (supp\ x - as) \cup (supp\ x \cap as) \cup (p' \cdot ((supp\ x - as) \cup (supp\ x \cap as)))$
using b **by** $simp$
also have $\dots = (supp\ x - as) \cup (supp\ x \cap as) \cup ((p' \cdot (supp\ x - as)) \cup (p' \cdot (supp\ x \cap as)))$
by $(simp\ add: union-eqvt)$
also have $\dots = (supp\ x - as) \cup (supp\ x \cap as) \cup (p' \cdot (supp\ x \cap as))$
using $\#$ **by** $auto$
also have $\dots = (supp\ x - as) \cup (supp\ x \cap as) \cup (supp\ x' \cap as')$ **using** asm
by $(simp\ add: supp-property-res)$
finally have $supp\ p \subseteq (supp\ x - as) \cup (supp\ x \cap as) \cup (supp\ x' \cap as')$.
then
have $supp\ p \subseteq (supp\ x \cap as) \cup (supp\ x' \cap as')$ **using** 2 **by** $auto$
moreover
have $(as, x) \approx_{res} (=) supp\ p (as', x')$ **using** $asm\ 1\ a$ **by** $(simp\ add: alphas)$
ultimately
show $\exists p. (as, x) \approx_{res} (=) supp\ p (as', x') \wedge supp\ p \subseteq (supp\ x \cap as) \cup (supp\ x' \cap as')$ **by** $blast$
qed

lemma $alpha-abs-res-minimal:$

assumes $asm: (as, x) \approx_{res} (=) supp\ p (as', x')$
shows $(as \cap supp\ x, x) \approx_{res} (=) supp\ p (as' \cap supp\ x', x')$
using asm **unfolding** $alpha-res$ **by** $(auto\ simp: Diff-Int)$

lemma $alpha-abs-res-abs-set:$

assumes $asm: (as, x) \approx_{res} (=) supp\ p (as', x')$
shows $(as \cap supp\ x, x) \approx_{set} (=) supp\ p (as' \cap supp\ x', x')$

proof –

have $c:$ $p \cdot x = x'$
using $alpha-abs-res-minimal[OF\ asm]$ **unfolding** $alpha-res$ **by** $clarify$
then have $a:$ $supp\ x - as \cap supp\ x = supp\ (p \cdot x) - as' \cap supp\ (p \cdot x)$

using *alpha-abs-res-minimal*[*OF asm*] **by** (*simp add: alpha-res*)
have *b*: $(\text{supp } x - \text{as} \cap \text{supp } x) \#* p$
using *alpha-abs-res-minimal*[*OF asm*] **unfolding** *alpha-res* **by** *clarify*
have $p \cdot (\text{as} \cap \text{supp } x) = \text{as}' \cap \text{supp } (p \cdot x)$
by (*metis Int-commute asm c supp-property-res*)
then show *?thesis* **using** *a b c* **unfolding** *alpha-set* **by** *simp*
qed

lemma *alpha-abs-set-abs-res*:

assumes *asm*: $(\text{as} \cap \text{supp } x, x) \approx_{\text{set}} (=) \text{supp } p (\text{as}' \cap \text{supp } x', x')$
shows $(\text{as}, x) \approx_{\text{res}} (=) \text{supp } p (\text{as}', x')$
using *asm* **unfolding** *alphas* **by** (*auto simp: Diff-Int*)

lemma *alpha-abs-res-stronger1*:

assumes *asm*: $(\text{as}, x) \approx_{\text{res}} (=) \text{supp } p' (\text{as}', x')$
shows $\exists p. (\text{as}, x) \approx_{\text{res}} (=) \text{supp } p (\text{as}', x') \wedge \text{supp } p \subseteq \text{as} \cup \text{as}'$
using *alpha-abs-res-stronger1-aux*[*OF asm*] **by** *auto*

lemma *alpha-abs-set-stronger1*:

assumes *asm*: $(\text{as}, x) \approx_{\text{set}} (=) \text{supp } p' (\text{as}', x')$
shows $\exists p. (\text{as}, x) \approx_{\text{set}} (=) \text{supp } p (\text{as}', x') \wedge \text{supp } p \subseteq \text{as} \cup \text{as}'$
proof –

from *asm* **have** *0*: $(\text{supp } x - \text{as}) \#* p'$ **by** (*auto simp only: alphas*)
then have *#*: $p' \cdot (\text{supp } x - \text{as}) = (\text{supp } x - \text{as})$
by (*simp add: atom-set-perm-eq*)
obtain *p* **where** ***: $\forall b \in (\text{supp } x \cup \text{as}). p \cdot b = p' \cdot b$
and ****: $\text{supp } p \subseteq (\text{supp } x \cup \text{as}) \cup p' \cdot (\text{supp } x \cup \text{as})$
using *set-renaming-perm2* **by** *blast*
from *** **have** $\forall b \in \text{supp } x. p \cdot b = p' \cdot b$ **by** *blast*
then have *a*: $p \cdot x = p' \cdot x$ **using** *supp-perm-perm-eq* **by** *auto*
from *** **have** $\forall b \in \text{as}. p \cdot b = p' \cdot b$ **by** *blast*
then have *zb*: $p \cdot \text{as} = p' \cdot \text{as}$
apply(*auto simp: permute-set-def*)
apply(*rule-tac x=xa in exI*)
apply(*simp*)
done
have *zc*: $p' \cdot \text{as} = \text{as}'$ **using** *asm* **by** (*simp add: alphas*)
from *0* **have** *1*: $(\text{supp } x - \text{as}) \#* p$ **using** ***
by (*auto simp: fresh-star-def fresh-perm*)
then have *2*: $(\text{supp } x - \text{as}) \cap \text{supp } p = \{\}$
by (*auto simp: fresh-star-def fresh-def*)
have *b*: $\text{supp } x = (\text{supp } x - \text{as}) \cup (\text{supp } x \cap \text{as})$ **by** *auto*
have $\text{supp } p \subseteq \text{supp } x \cup \text{as} \cup p' \cdot \text{supp } x \cup p' \cdot \text{as}$ **using** **** **using** *union-eqvt*
by *blast*
also have $\dots = (\text{supp } x - \text{as}) \cup (\text{supp } x \cap \text{as}) \cup \text{as} \cup (p' \cdot ((\text{supp } x - \text{as}) \cup (\text{supp } x \cap \text{as}))) \cup p' \cdot \text{as}$
using *b* **by** *simp*
also have $\dots = (\text{supp } x - \text{as}) \cup (\text{supp } x \cap \text{as}) \cup \text{as} \cup ((p' \cdot (\text{supp } x - \text{as})) \cup (p' \cdot (\text{supp } x \cap \text{as}))) \cup p' \cdot \text{as}$ **by** (*simp add: union-eqvt*)

also have $\dots = (\text{supp } x - \text{as}) \cup (\text{supp } x \cap \text{as}) \cup \text{as} \cup (p' \cdot (\text{supp } x \cap \text{as})) \cup p' \cdot \text{as}$
using $\#$ **by** *auto*
also have $\dots = (\text{supp } x - \text{as}) \cup (\text{supp } x \cap \text{as}) \cup \text{as} \cup p' \cdot ((\text{supp } x \cap \text{as}) \cup \text{as})$
using *union-eqvt*
by *auto*
also have $\dots = (\text{supp } x - \text{as}) \cup (\text{supp } x \cap \text{as}) \cup \text{as} \cup p' \cdot \text{as}$
by (*metis Int-commute Un-commute sup-inf-absorb*)
also have $\dots = (\text{supp } x - \text{as}) \cup \text{as} \cup p' \cdot \text{as}$ **by** *blast*
finally have $\text{supp } p \subseteq (\text{supp } x - \text{as}) \cup \text{as} \cup p' \cdot \text{as}$.
then have $\text{supp } p \subseteq \text{as} \cup p' \cdot \text{as}$ **using** \mathcal{Q} **by** *blast*
moreover
have $(\text{as}, x) \approx_{\text{set}} (=) \text{supp } p (\text{as}', x')$ **using** *asm 1 a zb* **by** (*simp add: alphas*)
ultimately
show $\exists p. (\text{as}, x) \approx_{\text{set}} (=) \text{supp } p (\text{as}', x') \wedge \text{supp } p \subseteq \text{as} \cup \text{as}'$ **using** *zc* **by**
blast
qed

lemma *alpha-abs-lst-stronger1*:

assumes *asm*: $(\text{as}, x) \approx_{\text{lst}} (=) \text{supp } p' (\text{as}', x')$
shows $\exists p. (\text{as}, x) \approx_{\text{lst}} (=) \text{supp } p (\text{as}', x') \wedge \text{supp } p \subseteq \text{set } \text{as} \cup \text{set } \text{as}'$
proof –
from *asm* **have** 0 : $(\text{supp } x - \text{set } \text{as}) \#* p'$ **by** (*auto simp only: alphas*)
then have $\#$: $p' \cdot (\text{supp } x - \text{set } \text{as}) = (\text{supp } x - \text{set } \text{as})$
by (*simp add: atom-set-perm-eq*)
obtain p **where** $*$: $\forall b \in (\text{supp } x \cup \text{set } \text{as}). p \cdot b = p' \cdot b$
and $**$: $\text{supp } p \subseteq (\text{supp } x \cup \text{set } \text{as}) \cup p' \cdot (\text{supp } x \cup \text{set } \text{as})$
using *set-renaming-perm2* **by** *blast*
from $*$ **have** $\forall b \in \text{supp } x. p \cdot b = p' \cdot b$ **by** *blast*
then have a : $p \cdot x = p' \cdot x$ **using** *supp-perm-perm-eq* **by** *auto*
from $*$ **have** $\forall b \in \text{set } \text{as}. p \cdot b = p' \cdot b$ **by** *blast*
then have zb : $p \cdot \text{as} = p' \cdot \text{as}$ **by** (*induct as*) (*auto*)
have zc : $p' \cdot \text{set } \text{as} = \text{set } \text{as}'$ **using** *asm* **by** (*simp add: alphas set-eqvt*)
from 0 **have** 1 : $(\text{supp } x - \text{set } \text{as}) \#* p$ **using** $*$
by (*auto simp: fresh-star-def fresh-perm*)
then have 2 : $(\text{supp } x - \text{set } \text{as}) \cap \text{supp } p = \{\}$
by (*auto simp: fresh-star-def fresh-def*)
have b : $\text{supp } x = (\text{supp } x - \text{set } \text{as}) \cup (\text{supp } x \cap \text{set } \text{as})$ **by** *auto*
have $\text{supp } p \subseteq \text{supp } x \cup \text{set } \text{as} \cup p' \cdot \text{supp } x \cup p' \cdot \text{set } \text{as}$ **using** $**$ **using**
union-eqvt **by** *blast*
also have $\dots = (\text{supp } x - \text{set } \text{as}) \cup (\text{supp } x \cap \text{set } \text{as}) \cup \text{set } \text{as} \cup$
 $(p' \cdot ((\text{supp } x - \text{set } \text{as}) \cup (\text{supp } x \cap \text{set } \text{as}))) \cup p' \cdot \text{set } \text{as}$ **using** b **by** *simp*
also have $\dots = (\text{supp } x - \text{set } \text{as}) \cup (\text{supp } x \cap \text{set } \text{as}) \cup \text{set } \text{as} \cup$
 $((p' \cdot (\text{supp } x - \text{set } \text{as})) \cup (p' \cdot (\text{supp } x \cap \text{set } \text{as}))) \cup p' \cdot \text{set } \text{as}$ **by** (*simp add:*
union-eqvt)
also have $\dots = (\text{supp } x - \text{set } \text{as}) \cup (\text{supp } x \cap \text{set } \text{as}) \cup \text{set } \text{as} \cup$
 $(p' \cdot (\text{supp } x \cap \text{set } \text{as})) \cup p' \cdot \text{set } \text{as}$ **using** $\#$ **by** *auto*
also have $\dots = (\text{supp } x - \text{set } \text{as}) \cup (\text{supp } x \cap \text{set } \text{as}) \cup \text{set } \text{as} \cup p' \cdot ((\text{supp } x$
 $\cap \text{set } \text{as}) \cup \text{set } \text{as})$

using *union-eqt* **by** *auto*
also have $\dots = (\text{supp } x - \text{set } as) \cup (\text{supp } x \cap \text{set } as) \cup \text{set } as \cup p' \cdot \text{set } as$
by (*metis Int-commute Un-commute sup-inf-absorb*)
also have $\dots = (\text{supp } x - \text{set } as) \cup \text{set } as \cup p' \cdot \text{set } as$ **by** *blast*
finally have $\text{supp } p \subseteq (\text{supp } x - \text{set } as) \cup \text{set } as \cup p' \cdot \text{set } as$.
then have $\text{supp } p \subseteq \text{set } as \cup p' \cdot \text{set } as$ **using** 2 **by** *blast*
moreover
have $(as, x) \approx_{\text{lst}} (=) \text{supp } p (as', x')$ **using** *asm 1 a zb* **by** (*simp add: alphas*)
ultimately
show $\exists p. (as, x) \approx_{\text{lst}} (=) \text{supp } p (as', x') \wedge \text{supp } p \subseteq \text{set } as \cup \text{set } as'$ **using** *zc*
by *blast*
qed

lemma *alphas-abs-stronger*:

shows $(as, x) \approx_{\text{abs-set}} (as', x') \longleftrightarrow (\exists p. (as, x) \approx_{\text{set}} (=) \text{supp } p (as', x') \wedge \text{supp } p \subseteq as \cup as')$
and $(as, x) \approx_{\text{abs-res}} (as', x') \longleftrightarrow (\exists p. (as, x) \approx_{\text{res}} (=) \text{supp } p (as', x') \wedge \text{supp } p \subseteq as \cup as')$
and $(bs, x) \approx_{\text{abs-lst}} (bs', x') \longleftrightarrow$
 $(\exists p. (bs, x) \approx_{\text{lst}} (=) \text{supp } p (bs', x') \wedge \text{supp } p \subseteq \text{set } bs \cup \text{set } bs')$
apply(*rule iffI*)
apply(*auto simp: alphas-abs alpha-abs-set-stronger1*)[1]
apply(*auto simp: alphas-abs*)[1]
apply(*rule iffI*)
apply(*auto simp: alphas-abs alpha-abs-res-stronger1*)[1]
apply(*auto simp: alphas-abs*)[1]
apply(*rule iffI*)
apply(*auto simp: alphas-abs alpha-abs-lst-stronger1*)[1]
apply(*auto simp: alphas-abs*)[1]
done

lemma *alpha-res-alpha-set*:

$(bs, x) \approx_{\text{res}} (=) \text{supp } p (cs, y) \longleftrightarrow (bs \cap \text{supp } x, x) \approx_{\text{set}} (=) \text{supp } p (cs \cap \text{supp } y, y)$
using *alpha-abs-set-abs-res alpha-abs-res-abs-set* **by** *blast*

31 Quotient types

quotient-type

$'a \text{ abs-set} = (\text{atom set} \times 'a::\text{pt}) / \text{alpha-abs-set}$

apply(*rule equivpI*)

unfolding *reflp-def refl-on-def symp-def sym-def transp-def trans-def*

by (*auto intro: alphas-abs-sym alphas-abs-refl alphas-abs-trans simp only*.)

quotient-type

$'b \text{ abs-res} = (\text{atom set} \times 'b::\text{pt}) / \text{alpha-abs-res}$

apply(*rule equivpI*)

unfolding *reflp-def refl-on-def symp-def sym-def transp-def trans-def*

by (*auto intro: alphas-abs-sym alphas-abs-refl alphas-abs-trans simp only*.)

quotient-type

'c abs-*lst* = (atom *list* × 'c::pt) / alpha-abs-*lst*
apply(rule-tac [!] equivpI)
unfolding reflp-def refl-on-def symp-def sym-def transp-def trans-def
by (auto intro: alphas-abs-sym alphas-abs-refl alphas-abs-trans simp only:)

quotient-definition

Abs-set ([-]set. - [60, 60] 60)
where
 Abs-set::atom set ⇒ ('a::pt) ⇒ 'a abs-set
is
 Pair::atom set ⇒ ('a::pt) ⇒ (atom set × 'a) .

quotient-definition

Abs-res ([-]res. - [60, 60] 60)
where
 Abs-res::atom set ⇒ ('a::pt) ⇒ 'a abs-res
is
 Pair::atom set ⇒ ('a::pt) ⇒ (atom set × 'a) .

quotient-definition

Abs-*lst* ([-]*lst*. - [60, 60] 60)
where
 Abs-*lst*::atom list ⇒ ('a::pt) ⇒ 'a abs-*lst*
is
 Pair::atom list ⇒ ('a::pt) ⇒ (atom list × 'a) .

lemma [quot-respect]:

shows ((=) ==> (=) ==> alpha-abs-set) Pair Pair
and ((=) ==> (=) ==> alpha-abs-res) Pair Pair
and ((=) ==> (=) ==> alpha-abs-*lst*) Pair Pair
unfolding rel-fun-def
by (auto intro: alphas-abs-refl)

lemma [quot-respect]:

shows ((=) ==> alpha-abs-set ==> alpha-abs-set) permute permute
and ((=) ==> alpha-abs-res ==> alpha-abs-res) permute permute
and ((=) ==> alpha-abs-*lst* ==> alpha-abs-*lst*) permute permute
unfolding rel-fun-def
by (auto intro: alphas-abs-*eqvt* simp only: Pair-*eqvt*)

lemma Abs-*eq-iff*:

shows [bs]set. x = [bs]set. y ↔ (∃ p. (bs, x) ≈set (=) supp p (bs', y))
and [bs]res. x = [bs]res. y ↔ (∃ p. (bs, x) ≈res (=) supp p (bs', y))
and [cs]*lst*. x = [cs]*lst*. y ↔ (∃ p. (cs, x) ≈*lst* (=) supp p (cs', y))
by (lifting alphas-abs)

lemma Abs-*eq-iff2*:

shows $[bs]set. x = [bs']set. y \longleftrightarrow (\exists p. (bs, x) \approx_{set} (=) supp p (bs', y) \wedge supp p \subseteq bs \cup bs')$
and $[bs]res. x = [bs']res. y \longleftrightarrow (\exists p. (bs, x) \approx_{res} (=) supp p (bs', y) \wedge supp p \subseteq bs \cup bs')$
and $[cs]lst. x = [cs']lst. y \longleftrightarrow (\exists p. (cs, x) \approx_{lst} (=) supp p (cs', y) \wedge supp p \subseteq set cs \cup set cs')$
by (*lifting alphas-abs-stronger*)

lemma *Abs-eq-res-set*:

shows $[bs]res. x = [cs]res. y \longleftrightarrow [bs \cap supp x]set. x = [cs \cap supp y]set. y$
unfolding *Abs-eq-iff alpha-res-alpha-set* **by** *rule*

lemma *Abs-eq-res-supp*:

assumes *asm*: $supp x \subseteq bs$
shows $[as]res. x = [as \cap bs]res. x$
unfolding *Abs-eq-iff alphas*
apply (*rule-tac x=0::perm in exI*)
apply (*simp add: fresh-star-zero*)
using *asm* **by** *blast*

lemma *Abs-exhausts[cases type]*:

shows $(\bigwedge as (x::'a::pt). y1 = [as]set. x \implies P1) \implies P1$
and $(\bigwedge as (x::'a::pt). y2 = [as]res. x \implies P2) \implies P2$
and $(\bigwedge bs (x::'a::pt). y3 = [bs]lst. x \implies P3) \implies P3$
by (*lifting prod.exhaust[where 'a=atom set and 'b='a]*
prod.exhaust[where 'a=atom set and 'b='a]
prod.exhaust[where 'a=atom list and 'b='a])

instantiation *abs-set* :: $(pt) pt$

begin

quotient-definition

permute-abs-set::perm $\Rightarrow ('a::pt abs-set) \Rightarrow 'a abs-set$

is

permute::perm $\Rightarrow (atom set \times 'a::pt) \Rightarrow (atom set \times 'a::pt)$

by (*auto intro: alphas-abs-eqvt simp only: Pair-eqvt*)

lemma *permute-Abs-set[simp]*:

fixes $x::'a::pt$

shows $(p \cdot ([as]set. x)) = [p \cdot as]set. (p \cdot x)$

by (*lifting permute-prod.simps[where 'a=atom set and 'b='a]*)

instance

apply *standard*

apply (*case-tac [!] x*)

apply (*simp-all*)

done

end

instantiation *abs-res* :: (pt) pt
begin

quotient-definition

permute-abs-res::perm \Rightarrow ('a::pt *abs-res*) \Rightarrow 'a *abs-res*

is

permute:: perm \Rightarrow (atom set \times 'a::pt) \Rightarrow (atom set \times 'a::pt)
by (auto intro: *alphas-abs-eqv* simp only: *Pair-eqv*)

lemma *permute-Abs-res[simp]*:

fixes *x*::'a::pt

shows ($p \cdot ([as]res. x)$) = [$p \cdot as$]res. ($p \cdot x$)

by (*lifting permute-prod.simps*[**where** 'a=atom set **and** 'b='a])

instance

apply *standard*

apply(*case-tac* [!] *x*)

apply(*simp-all*)

done

end

instantiation *abs-lst* :: (pt) pt
begin

quotient-definition

permute-abs-lst::perm \Rightarrow ('a::pt *abs-lst*) \Rightarrow 'a *abs-lst*

is

permute:: perm \Rightarrow (atom list \times 'a::pt) \Rightarrow (atom list \times 'a::pt)
by (auto intro: *alphas-abs-eqv* simp only: *Pair-eqv*)

lemma *permute-Abs-lst[simp]*:

fixes *x*::'a::pt

shows ($p \cdot ([as]lst. x)$) = [$p \cdot as$]lst. ($p \cdot x$)

by (*lifting permute-prod.simps*[**where** 'a=atom list **and** 'b='a])

instance

apply *standard*

apply(*case-tac* [!] *x*)

apply(*simp-all*)

done

end

lemmas *permute-Abs*[*eqvt*] = *permute-Abs-set permute-Abs-res permute-Abs-lst*

lemma *Abs-swap1*:

assumes $a1: a \notin (\text{supp } x) - bs$
and $a2: b \notin (\text{supp } x) - bs$
shows $[bs]set. x = [(a \rightleftharpoons b) \cdot bs]set. ((a \rightleftharpoons b) \cdot x)$
and $[bs]res. x = [(a \rightleftharpoons b) \cdot bs]res. ((a \rightleftharpoons b) \cdot x)$
unfolding *Abs-eq-iff*
unfolding *alphas*
unfolding *supp-eqvt[symmetric] Diff-eqvt[symmetric]*
unfolding *fresh-star-def fresh-def*
unfolding *swap-set-not-in[OF a1 a2]*
using $a1 a2$
by (*rule-tac* [!] $x=(a \rightleftharpoons b)$ **in** exI)
(*auto simp: supp-perm swap-atom*)

lemma *Abs-swap2*:

assumes $a1: a \notin (\text{supp } x) - (\text{set } bs)$
and $a2: b \notin (\text{supp } x) - (\text{set } bs)$
shows $[bs]lst. x = [(a \rightleftharpoons b) \cdot bs]lst. ((a \rightleftharpoons b) \cdot x)$
unfolding *Abs-eq-iff*
unfolding *alphas*
unfolding *supp-eqvt[symmetric] Diff-eqvt[symmetric] set-eqvt[symmetric]*
unfolding *fresh-star-def fresh-def*
unfolding *swap-set-not-in[OF a1 a2]*
using $a1 a2$
by (*rule-tac* [!] $x=(a \rightleftharpoons b)$ **in** exI)
(*auto simp: supp-perm swap-atom*)

lemma *Abs-supports*:

shows $((\text{supp } x) - as)$ *supports* $([as]set. x)$
and $((\text{supp } x) - as)$ *supports* $([as]res. x)$
and $((\text{supp } x) - \text{set } bs)$ *supports* $([bs]lst. x)$
unfolding *supports-def*
unfolding *permute-Abs*
by (*simp-all add: Abs-swap1[symmetric] Abs-swap2[symmetric]*)

function

supp-set :: $('a::pt)$ *abs-set* \Rightarrow *atom set* **and**
supp-res :: $('a::pt)$ *abs-res* \Rightarrow *atom set* **and**
supp-lst :: $('a::pt)$ *abs-lst* \Rightarrow *atom set*

where

$supp\text{-set } ([as]set. x) = \text{supp } x - as$
 $| \text{supp}\text{-res } ([as]res. x) = \text{supp } x - as$
 $| \text{supp}\text{-lst } (Abs\text{-lst } cs\ x) = (\text{supp } x) - (\text{set } cs)$
apply(*simp-all add: Abs-eq-iff alphas-abs alphas*)
apply(*case-tac x*)
apply(*case-tac a*)
apply(*simp*)
apply(*case-tac b*)
apply(*case-tac a*)

apply(*simp*)
apply(*case-tac ba*)
apply(*simp*)
done

termination
by *lexicographic-order*

lemma *supp-funs-eqvt*[*eqvt*]:
shows $(p \cdot \text{supp-set } x) = \text{supp-set } (p \cdot x)$
and $(p \cdot \text{supp-res } y) = \text{supp-res } (p \cdot y)$
and $(p \cdot \text{supp-lst } z) = \text{supp-lst } (p \cdot z)$
apply(*case-tac x*)
apply(*simp*)
apply(*case-tac y*)
apply(*simp*)
apply(*case-tac z*)
apply(*simp*)
done

lemma *Abs-fresh-aux*:
shows $a \# [bs]\text{set. } x \implies a \# \text{supp-set } ([bs]\text{set. } x)$
and $a \# [bs]\text{res. } x \implies a \# \text{supp-res } ([bs]\text{res. } x)$
and $a \# [cs]\text{lst. } x \implies a \# \text{supp-lst } ([cs]\text{lst. } x)$
by (*rule-tac* [!] *fresh-fun-eqvt-app*)
(auto simp only: eqvt-def eqvts-raw)

lemma *Abs-supp-subset1*:
assumes *a: finite (supp x)*
shows $(\text{supp } x) - as \subseteq \text{supp } ([as]\text{set. } x)$
and $(\text{supp } x) - as \subseteq \text{supp } ([as]\text{res. } x)$
and $(\text{supp } x) - (\text{set } bs) \subseteq \text{supp } ([bs]\text{lst. } x)$
unfolding *supp-conv-fresh*
by (*auto dest!: Abs-fresh-aux*)
(simp-all add: fresh-def supp-finite-atom-set a)

lemma *Abs-supp-subset2*:
assumes *a: finite (supp x)*
shows $\text{supp } ([as]\text{set. } x) \subseteq (\text{supp } x) - as$
and $\text{supp } ([as]\text{res. } x) \subseteq (\text{supp } x) - as$
and $\text{supp } ([bs]\text{lst. } x) \subseteq (\text{supp } x) - (\text{set } bs)$
by (*rule-tac* [!] *supp-is-subset*)
(simp-all add: Abs-supports a)

lemma *Abs-finite-supp*:
assumes *a: finite (supp x)*
shows $\text{supp } ([as]\text{set. } x) = (\text{supp } x) - as$
and $\text{supp } ([as]\text{res. } x) = (\text{supp } x) - as$
and $\text{supp } ([bs]\text{lst. } x) = (\text{supp } x) - (\text{set } bs)$

using *Abs-supp-subset1*[*OF a*] *Abs-supp-subset2*[*OF a*]
by *blast+*

lemma *supp-Abs*:
fixes $x::'a::fs$
shows $supp ([as]set. x) = (supp x) - as$
and $supp ([as]res. x) = (supp x) - as$
and $supp ([bs]lst. x) = (supp x) - (set bs)$
by (*simp-all add: Abs-finite-supp finite-supp*)

instance *abs-set* :: (*fs*) *fs*
apply *standard*
apply(*case-tac x*)
apply(*simp add: supp-Abs finite-supp*)
done

instance *abs-res* :: (*fs*) *fs*
apply *standard*
apply(*case-tac x*)
apply(*simp add: supp-Abs finite-supp*)
done

instance *abs-lst* :: (*fs*) *fs*
apply *standard*
apply(*case-tac x*)
apply(*simp add: supp-Abs finite-supp*)
done

lemma *Abs-fresh-iff*:
fixes $x::'a::fs$
shows $a \# [bs]set. x \longleftrightarrow a \in bs \vee (a \notin bs \wedge a \# x)$
and $a \# [bs]res. x \longleftrightarrow a \in bs \vee (a \notin bs \wedge a \# x)$
and $a \# [cs]lst. x \longleftrightarrow a \in (set cs) \vee (a \notin (set cs) \wedge a \# x)$
unfolding *fresh-def*
unfolding *supp-Abs*
by *auto*

lemma *Abs-fresh-star-iff*:
fixes $x::'a::fs$
shows $as \#* ([bs]set. x) \longleftrightarrow (as - bs) \#* x$
and $as \#* ([bs]res. x) \longleftrightarrow (as - bs) \#* x$
and $as \#* ([cs]lst. x) \longleftrightarrow (as - set cs) \#* x$
unfolding *fresh-star-def*
by (*auto simp: Abs-fresh-iff*)

lemma *Abs-fresh-star*:
fixes $x::'a::fs$
shows $as \subseteq as' \implies as \#* ([as']set. x)$
and $as \subseteq as' \implies as \#* ([as']res. x)$

and $bs \subseteq \text{set } bs' \implies bs \#* ([bs]lst. x)$
unfolding *fresh-star-def*
by(*auto simp: Abs-fresh-iff*)

lemma *Abs-fresh-star2*:

fixes $x::'a::fs$
shows $as \cap bs = \{\} \implies as \#* ([bs]set. x) \longleftrightarrow as \#* x$
and $as \cap bs = \{\} \implies as \#* ([bs]res. x) \longleftrightarrow as \#* x$
and $cs \cap \text{set } ds = \{\} \implies cs \#* ([ds]lst. x) \longleftrightarrow cs \#* x$
unfolding *fresh-star-def Abs-fresh-iff*
by *auto*

32 Abstractions of single atoms

lemma *Abs1-eq*:

fixes $x y::'a::fs$
shows $[\{atom\ a\}]set. x = [\{atom\ a\}]set. y \longleftrightarrow x = y$
and $[\{atom\ a\}]res. x = [\{atom\ a\}]res. y \longleftrightarrow x = y$
and $[[atom\ a]]lst. x = [[atom\ a]]lst. y \longleftrightarrow x = y$
unfolding *Abs-eq-iff2 alphas*
by (*auto simp: supp-perm-singleton fresh-star-def fresh-zero-perm*)

lemma *Abs1-eq-iff-fresh*:

fixes $x y::'a::fs$
and $a b c::'b::at$
assumes $atom\ c \# (a, b, x, y)$
shows $[\{atom\ a\}]set. x = [\{atom\ b\}]set. y \longleftrightarrow (a \leftrightarrow c) \cdot x = (b \leftrightarrow c) \cdot y$
and $[\{atom\ a\}]res. x = [\{atom\ b\}]res. y \longleftrightarrow (a \leftrightarrow c) \cdot x = (b \leftrightarrow c) \cdot y$
and $[[atom\ a]]lst. x = [[atom\ b]]lst. y \longleftrightarrow (a \leftrightarrow c) \cdot x = (b \leftrightarrow c) \cdot y$
proof –
have $[\{atom\ a\}]set. x = (a \leftrightarrow c) \cdot ([\{atom\ a\}]set. x)$
by (*rule-tac flip-fresh-fresh[symmetric]*) (*simp-all add: Abs-fresh-iff assms*)
then have $[\{atom\ a\}]set. x = [\{atom\ c\}]set. ((a \leftrightarrow c) \cdot x)$ **by** *simp*
moreover
have $[\{atom\ b\}]set. y = (b \leftrightarrow c) \cdot ([\{atom\ b\}]set. y)$
by (*rule-tac flip-fresh-fresh[symmetric]*) (*simp-all add: Abs-fresh-iff assms*)
then have $[\{atom\ b\}]set. y = [\{atom\ c\}]set. ((b \leftrightarrow c) \cdot y)$ **by** *simp*
ultimately
show $[\{atom\ a\}]set. x = [\{atom\ b\}]set. y \longleftrightarrow (a \leftrightarrow c) \cdot x = (b \leftrightarrow c) \cdot y$
by (*simp add: Abs1-eq*)

next

have $[\{atom\ a\}]res. x = (a \leftrightarrow c) \cdot ([\{atom\ a\}]res. x)$
by (*rule-tac flip-fresh-fresh[symmetric]*) (*simp-all add: Abs-fresh-iff assms*)
then have $[\{atom\ a\}]res. x = [\{atom\ c\}]res. ((a \leftrightarrow c) \cdot x)$ **by** *simp*
moreover
have $[\{atom\ b\}]res. y = (b \leftrightarrow c) \cdot ([\{atom\ b\}]res. y)$
by (*rule-tac flip-fresh-fresh[symmetric]*) (*simp-all add: Abs-fresh-iff assms*)
then have $[\{atom\ b\}]res. y = [\{atom\ c\}]res. ((b \leftrightarrow c) \cdot y)$ **by** *simp*
ultimately


```

show [{atom a}]res. x = [{atom b}]res. y  $\longleftrightarrow$  (a  $\leftrightarrow$  c)  $\cdot$  x = (b  $\leftrightarrow$  c)  $\cdot$  y
  by (simp add: Abs1-eq)
next
have [[atom a]]lst. x = (a  $\leftrightarrow$  c)  $\cdot$  ([[atom a]]lst. x)
  by (rule-tac flip-fresh-fresh[symmetric]) (simp-all add: Abs-fresh-iff assms)
then have [[atom a]]lst. x = [[atom c]]lst. ((a  $\leftrightarrow$  c)  $\cdot$  x) by simp
moreover
have [[atom b]]lst. y = (b  $\leftrightarrow$  c)  $\cdot$  ([[atom b]]lst. y)
  by (rule-tac flip-fresh-fresh[symmetric]) (simp-all add: Abs-fresh-iff assms)
then have [[atom b]]lst. y = [[atom c]]lst. ((b  $\leftrightarrow$  c)  $\cdot$  y) by simp
ultimately
show [[atom a]]lst. x = [[atom b]]lst. y  $\longleftrightarrow$  (a  $\leftrightarrow$  c)  $\cdot$  x = (b  $\leftrightarrow$  c)  $\cdot$  y
  by (simp add: Abs1-eq)
qed

```

lemma Abs1-eq-iff-all:

```

fixes x y::'a::fs
and z::'c::fs
and a b::'b::at
shows [{atom a}]set. x = [{atom b}]set. y  $\longleftrightarrow$  ( $\forall$  c. atom c  $\#$  z  $\longrightarrow$  atom c  $\#$ 
(a, b, x, y)  $\longrightarrow$  (a  $\leftrightarrow$  c)  $\cdot$  x = (b  $\leftrightarrow$  c)  $\cdot$  y)
and [{atom a}]res. x = [{atom b}]res. y  $\longleftrightarrow$  ( $\forall$  c. atom c  $\#$  z  $\longrightarrow$  atom c  $\#$  (a,
b, x, y)  $\longrightarrow$  (a  $\leftrightarrow$  c)  $\cdot$  x = (b  $\leftrightarrow$  c)  $\cdot$  y)
and [[atom a]]lst. x = [[atom b]]lst. y  $\longleftrightarrow$  ( $\forall$  c. atom c  $\#$  z  $\longrightarrow$  atom c  $\#$  (a, b,
x, y)  $\longrightarrow$  (a  $\leftrightarrow$  c)  $\cdot$  x = (b  $\leftrightarrow$  c)  $\cdot$  y)
apply(auto)
apply(simp add: Abs1-eq-iff-fresh(1)[symmetric])
apply(rule-tac ?'a='b::at and x=(a, b, x, y, z) in obtain-fresh)
apply(drule-tac x=aa in spec)
apply(simp)
apply(subst Abs1-eq-iff-fresh(1))
apply(auto simp: fresh-Pair)[2]
apply(simp add: Abs1-eq-iff-fresh(2)[symmetric])
apply(rule-tac ?'a='b::at and x=(a, b, x, y, z) in obtain-fresh)
apply(drule-tac x=aa in spec)
apply(simp)
apply(subst Abs1-eq-iff-fresh(2))
apply(auto simp: fresh-Pair)[2]
apply(simp add: Abs1-eq-iff-fresh(3)[symmetric])
apply(rule-tac ?'a='b::at and x=(a, b, x, y, z) in obtain-fresh)
apply(drule-tac x=aa in spec)
apply(simp)
apply(subst Abs1-eq-iff-fresh(3))
apply(auto simp: fresh-Pair)[2]
done

```

lemma Abs1-eq-iff:

```

fixes x y::'a::fs
and a b::'b::at

```

shows $[\{atom\ a\}]set. x = [\{atom\ b\}]set. y \longleftrightarrow (a = b \wedge x = y) \vee (a \neq b \wedge x = (a \leftrightarrow b) \cdot y \wedge atom\ a \# y)$
and $[\{atom\ a\}]res. x = [\{atom\ b\}]res. y \longleftrightarrow (a = b \wedge x = y) \vee (a \neq b \wedge x = (a \leftrightarrow b) \cdot y \wedge atom\ a \# y)$
and $[[atom\ a]]lst. x = [[atom\ b]]lst. y \longleftrightarrow (a = b \wedge x = y) \vee (a \neq b \wedge x = (a \leftrightarrow b) \cdot y \wedge atom\ a \# y)$
proof –
 { **assume** $a = b$
 then have $[\{atom\ a\}]set. x = [\{atom\ b\}]set. y \longleftrightarrow (a = b \wedge x = y)$ **by** (*simp add: Abs1-eq*)
 }
 moreover
 { **assume** $*$: $a \neq b$ **and** $**$: $[\{atom\ a\}]set. x = [\{atom\ b\}]set. y$
 have $\#$: $atom\ a \# [\{atom\ b\}]set. y$ **by** (*simp add: *[symmetric] Abs-fresh-iff*)
 have $[\{atom\ a\}]set. ((a \leftrightarrow b) \cdot y) = (a \leftrightarrow b) \cdot ([\{atom\ b\}]set. y)$ **by** (*simp*)
 also have $\dots = [\{atom\ b\}]set. y$
 by (*rule flip-fresh-fresh*) (*simp add: #, simp add: Abs-fresh-iff*)
 also have $\dots = [\{atom\ a\}]set. x$ **using** $**$ **by** *simp*
 finally have $a \neq b \wedge x = (a \leftrightarrow b) \cdot y \wedge atom\ a \# y$ **using** $\# *$ **by** (*simp add: Abs1-eq Abs-fresh-iff*)
 }
 moreover
 { **assume** $*$: $a \neq b$ **and** $**$: $x = (a \leftrightarrow b) \cdot y \wedge atom\ a \# y$
 have $[\{atom\ a\}]set. x = [\{atom\ a\}]set. ((a \leftrightarrow b) \cdot y)$ **using** $**$ **by** *simp*
 also have $\dots = (a \leftrightarrow b) \cdot ([\{atom\ b\}]set. y)$ **by** (*simp add: permute-set-def*)
 also have $\dots = [\{atom\ b\}]set. y$
 by (*rule flip-fresh-fresh*) (*simp add: Abs-fresh-iff **, simp add: Abs-fresh-iff*)
 finally have $[\{atom\ a\}]set. x = [\{atom\ b\}]set. y$.
 }
 ultimately
 show $[\{atom\ a\}]set. x = [\{atom\ b\}]set. y \longleftrightarrow (a = b \wedge x = y) \vee (a \neq b \wedge x = (a \leftrightarrow b) \cdot y \wedge atom\ a \# y)$
 by *blast*
next
 { **assume** $a = b$
 then have $Abs-res\ \{atom\ a\}\ x = Abs-res\ \{atom\ b\}\ y \longleftrightarrow (a = b \wedge x = y)$ **by** (*simp add: Abs1-eq*)
 }
 moreover
 { **assume** $*$: $a \neq b$ **and** $**$: $Abs-res\ \{atom\ a\}\ x = Abs-res\ \{atom\ b\}\ y$
 have $\#$: $atom\ a \# Abs-res\ \{atom\ b\}\ y$ **by** (*simp add: *[symmetric] Abs-fresh-iff*)
 have $Abs-res\ \{atom\ a\}\ ((a \leftrightarrow b) \cdot y) = (a \leftrightarrow b) \cdot (Abs-res\ \{atom\ b\}\ y)$ **by** *simp*
 also have $\dots = Abs-res\ \{atom\ b\}\ y$
 by (*rule flip-fresh-fresh*) (*simp add: #, simp add: Abs-fresh-iff*)
 also have $\dots = Abs-res\ \{atom\ a\}\ x$ **using** $**$ **by** *simp*
 finally have $a \neq b \wedge x = (a \leftrightarrow b) \cdot y \wedge atom\ a \# y$ **using** $\# *$ **by** (*simp add: Abs1-eq Abs-fresh-iff*)
 }
}

```

moreover
{ assume *:  $a \neq b$  and **:  $x = (a \leftrightarrow b) \cdot y \wedge \text{atom } a \# y$ 
  have  $\text{Abs-res } \{ \text{atom } a \} x = \text{Abs-res } \{ \text{atom } a \} ((a \leftrightarrow b) \cdot y)$  using ** by simp
  also have  $\dots = (a \leftrightarrow b) \cdot \text{Abs-res } \{ \text{atom } b \} y$  by (simp add: permute-set-def)
  also have  $\dots = \text{Abs-res } \{ \text{atom } b \} y$ 
    by (rule flip-fresh-fresh) (simp add: Abs-fresh-iff **, simp add: Abs-fresh-iff)
  finally have  $\text{Abs-res } \{ \text{atom } a \} x = \text{Abs-res } \{ \text{atom } b \} y$  .
}
ultimately
show  $\text{Abs-res } \{ \text{atom } a \} x = \text{Abs-res } \{ \text{atom } b \} y \longleftrightarrow (a = b \wedge x = y) \vee (a \neq b$ 
 $\wedge x = (a \leftrightarrow b) \cdot y \wedge \text{atom } a \# y)$ 
  by blast
next
{ assume  $a = b$ 
  then have  $\text{Abs-lst } [\text{atom } a] x = \text{Abs-lst } [\text{atom } b] y \longleftrightarrow (a = b \wedge x = y)$  by
(simp add: Abs1-eq)
}
moreover
{ assume *:  $a \neq b$  and **:  $\text{Abs-lst } [\text{atom } a] x = \text{Abs-lst } [\text{atom } b] y$ 
  have #:  $\text{atom } a \# \text{Abs-lst } [\text{atom } b] y$  by (simp add: **[symmetric] Abs-fresh-iff)
  have  $\text{Abs-lst } [\text{atom } a] ((a \leftrightarrow b) \cdot y) = (a \leftrightarrow b) \cdot (\text{Abs-lst } [\text{atom } b] y)$  by simp
  also have  $\dots = \text{Abs-lst } [\text{atom } b] y$ 
    by (rule flip-fresh-fresh) (simp add: #, simp add: Abs-fresh-iff)
  also have  $\dots = \text{Abs-lst } [\text{atom } a] x$  using ** by simp
  finally have  $a \neq b \wedge x = (a \leftrightarrow b) \cdot y \wedge \text{atom } a \# y$  using # * by (simp add:
Abs1-eq Abs-fresh-iff)
}
moreover
{ assume *:  $a \neq b$  and **:  $x = (a \leftrightarrow b) \cdot y \wedge \text{atom } a \# y$ 
  have  $\text{Abs-lst } [\text{atom } a] x = \text{Abs-lst } [\text{atom } a] ((a \leftrightarrow b) \cdot y)$  using ** by simp
  also have  $\dots = (a \leftrightarrow b) \cdot \text{Abs-lst } [\text{atom } b] y$  by simp
  also have  $\dots = \text{Abs-lst } [\text{atom } b] y$ 
    by (rule flip-fresh-fresh) (simp add: Abs-fresh-iff **, simp add: Abs-fresh-iff)
  finally have  $\text{Abs-lst } [\text{atom } a] x = \text{Abs-lst } [\text{atom } b] y$  .
}
ultimately
show  $\text{Abs-lst } [\text{atom } a] x = \text{Abs-lst } [\text{atom } b] y \longleftrightarrow (a = b \wedge x = y) \vee (a \neq b \wedge$ 
 $x = (a \leftrightarrow b) \cdot y \wedge \text{atom } a \# y)$ 
  by blast
qed

```

lemma *Abs1-eq-iff'*:

```

fixes  $x::'a::fs$ 
and  $a b::'b::at$ 
shows  $[\{ \text{atom } a \}] \text{set. } x = [\{ \text{atom } b \}] \text{set. } y \longleftrightarrow (a = b \wedge x = y) \vee (a \neq b \wedge (b$ 
 $\leftrightarrow a) \cdot x = y \wedge \text{atom } b \# x)$ 
and  $[\{ \text{atom } a \}] \text{res. } x = [\{ \text{atom } b \}] \text{res. } y \longleftrightarrow (a = b \wedge x = y) \vee (a \neq b \wedge (b$ 
 $\leftrightarrow a) \cdot x = y \wedge \text{atom } b \# x)$ 
and  $[[\text{atom } a]] \text{lst. } x = [[\text{atom } b]] \text{lst. } y \longleftrightarrow (a = b \wedge x = y) \vee (a \neq b \wedge (b \leftrightarrow$ 

```

$a) \cdot x = y \wedge \text{atom } b \# x$
by (*auto simp: Abs1-eq-iff fresh-permute-left*)

ML ‹

```

fun alpha-single-simproc thm - ctxt ctrm =
  let
    val thy = Proof-Context.theory-of ctxt
    val - $ (- $ x) $ (- $ y) = Thm.term-of ctrm
    val cvrs = union (op =) (Term.add-frees x []) (Term.add-frees y [])
      |> filter (fn (-, ty) => Sign.of-sort thy (ty, @ {sort fs}))
      |> map Free
      |> HOLogic.mk-tuple
      |> Thm.cterm-of ctxt
    val cvrs-ty = Thm.ctyp-of-cterm cvrs
    val thm' = thm
      |> Thm.instantiate' [NONE, NONE, SOME cvrs-ty] [NONE, NONE, NONE,
NONE, SOME cvrs]
    in
      SOME thm'
    end
  ›

```

simproc-setup *alpha-set* ($[\{\text{atom } a\}]_{\text{set}}. x = [\{\text{atom } b\}]_{\text{set}}. y$) =
 ‹*alpha-single-simproc* @ {*thm* *Abs1-eq-iff-all*(1)[*THEN* *eq-reflection*]}›

simproc-setup *alpha-res* ($[\{\text{atom } a\}]_{\text{res}}. x = [\{\text{atom } b\}]_{\text{res}}. y$) =
 ‹*alpha-single-simproc* @ {*thm* *Abs1-eq-iff-all*(2)[*THEN* *eq-reflection*]}›

simproc-setup *alpha-lst* ($[[\text{atom } a]]_{\text{lst}}. x = [[\text{atom } b]]_{\text{lst}}. y$) =
 ‹*alpha-single-simproc* @ {*thm* *Abs1-eq-iff-all*(3)[*THEN* *eq-reflection*]}›

32.1 Renaming of bodies of abstractions

lemma *Abs-rename-set*:

fixes $x::'a::fs$
assumes $a: (p \cdot bs) \#* x$

shows $\exists q. [bs]_{\text{set}}. x = [p \cdot bs]_{\text{set}}. (q \cdot x) \wedge q \cdot bs = p \cdot bs$

proof –

from *set-renaming-perm2*

obtain q **where** $*$: $\forall b \in bs. q \cdot b = p \cdot b$ **and** $**$: $\text{supp } q \subseteq bs \cup (p \cdot bs)$ **by**
blast

have $**$: $q \cdot bs = p \cdot bs$ **using** $*$

unfolding *permute-set-eq-image image-def* **by** *auto*

have $[bs]_{\text{set}}. x = q \cdot ([bs]_{\text{set}}. x)$

apply(*rule perm-supp-eq[symmetric]*)

using $a **$

unfolding *Abs-fresh-star-iff*

unfolding *fresh-star-def*
by *auto*
also have $\dots = [q \cdot bs]set. (q \cdot x)$ **by** *simp*
finally have $[bs]set. x = [p \cdot bs]set. (q \cdot x)$ **by** (*simp add: ****)
then show $\exists q. [bs]set. x = [p \cdot bs]set. (q \cdot x) \wedge q \cdot bs = p \cdot bs$ **using** ***** **by**
metis
qed

lemma *Abs-rename-res:*

fixes $x::'a::fs$
assumes $a: (p \cdot bs) \#* x$

shows $\exists q. [bs]res. x = [p \cdot bs]res. (q \cdot x) \wedge q \cdot bs = p \cdot bs$

proof –

from *set-renaming-perm2*

obtain q **where** $*$: $\forall b \in bs. q \cdot b = p \cdot b$ **and** $**$: $supp\ q \subseteq bs \cup (p \cdot bs)$ **by**

blast

have $***$: $q \cdot bs = p \cdot bs$ **using** $*$

unfolding *permute-set-eq-image image-def* **by** *auto*

have $[bs]res. x = q \cdot ([bs]res. x)$

apply(*rule perm-supp-eq[symmetric]*)

using a $**$

unfolding *Abs-fresh-star-iff*

unfolding *fresh-star-def*

by *auto*

also have $\dots = [q \cdot bs]res. (q \cdot x)$ **by** *simp*

finally have $[bs]res. x = [p \cdot bs]res. (q \cdot x)$ **by** (*simp add: ****)

then show $\exists q. [bs]res. x = [p \cdot bs]res. (q \cdot x) \wedge q \cdot bs = p \cdot bs$ **using** ***** **by**

metis

qed

lemma *Abs-rename-lst:*

fixes $x::'a::fs$

assumes $a: (p \cdot (set\ bs)) \#* x$

shows $\exists q. [bs]lst. x = [p \cdot bs]lst. (q \cdot x) \wedge q \cdot bs = p \cdot bs$

proof –

from *list-renaming-perm*

obtain q **where** $*$: $\forall b \in set\ bs. q \cdot b = p \cdot b$ **and** $**$: $supp\ q \subseteq set\ bs \cup (p \cdot set\ bs)$ **by** *blast*

have $***$: $q \cdot bs = p \cdot bs$ **using** $*$ **by** (*induct bs*) (*simp-all add: insert-eqt*)

have $[bs]lst. x = q \cdot ([bs]lst. x)$

apply(*rule perm-supp-eq[symmetric]*)

using a $**$

unfolding *Abs-fresh-star-iff*

unfolding *fresh-star-def*

by *auto*

also have $\dots = [q \cdot bs]lst. (q \cdot x)$ **by** *simp*

finally have $[bs]lst. x = [p \cdot bs]lst. (q \cdot x)$ **by** (*simp add: ****)

then show $\exists q. [bs]lst. x = [p \cdot bs]lst. (q \cdot x) \wedge q \cdot bs = p \cdot bs$ **using** ***** **by**

metis
qed

for deep recursive binders

lemma *Abs-rename-set'*:

fixes $x::'a::fs$
assumes $a: (p \cdot bs) \#* x$

shows $\exists q. [bs]set. x = [q \cdot bs]set. (q \cdot x) \wedge q \cdot bs = p \cdot bs$
using *Abs-rename-set[OF a]* **by** *metis*

lemma *Abs-rename-res'*:

fixes $x::'a::fs$
assumes $a: (p \cdot bs) \#* x$

shows $\exists q. [bs]res. x = [q \cdot bs]res. (q \cdot x) \wedge q \cdot bs = p \cdot bs$
using *Abs-rename-res[OF a]* **by** *metis*

lemma *Abs-rename-lst'*:

fixes $x::'a::fs$
assumes $a: (p \cdot (set\ bs)) \#* x$
shows $\exists q. [bs]lst. x = [q \cdot bs]lst. (q \cdot x) \wedge q \cdot bs = p \cdot bs$
using *Abs-rename-lst[OF a]* **by** *metis*

33 Infrastructure for building tuples of relations and functions

fun

prod-fv :: $('a \Rightarrow atom\ set) \Rightarrow ('b \Rightarrow atom\ set) \Rightarrow ('a \times 'b) \Rightarrow atom\ set$

where

prod-fv *fv1* *fv2* $(x, y) = fv1\ x \cup fv2\ y$

definition

prod-alpha :: $('a \Rightarrow 'a \Rightarrow bool) \Rightarrow ('b \Rightarrow 'b \Rightarrow bool) \Rightarrow ('a \times 'b \Rightarrow 'a \times 'b \Rightarrow bool)$

where

prod-alpha = *rel-prod*

lemma [*quot-respect*]:

shows $((R1 \implies (=)) \implies (R2 \implies (=)) \implies rel-prod\ R1\ R2 \implies (=))\ prod-fv\ prod-fv$
unfolding *rel-fun-def*
by *auto*

lemma [*quot-preserve*]:

assumes $q1: Quotient3\ R1\ abs1\ rep1$
and $q2: Quotient3\ R2\ abs2\ rep2$
shows $((abs1 \dashrightarrow id) \dashrightarrow (abs2 \dashrightarrow id) \dashrightarrow map-prod\ rep1\ rep2$

```

---> id) prod-fv = prod-fv
  by (simp add: fun-eq-iff Quotient3-abs-rep[OF q1] Quotient3-abs-rep[OF q2])

```

```

lemma [mono]:
  shows  $A \leq B \implies C \leq D \implies \text{prod-alpha } A \ C \leq \text{prod-alpha } B \ D$ 
  unfolding prod-alpha-def
  by auto

```

```

lemma [eqvt]:
  shows  $p \cdot \text{prod-alpha } A \ B \ x \ y = \text{prod-alpha } (p \cdot A) \ (p \cdot B) \ (p \cdot x) \ (p \cdot y)$ 
  unfolding prod-alpha-def
  unfolding rel-prod-conv
  by (perm-simp) (rule refl)

```

```

lemma [eqvt]:
  shows  $p \cdot \text{prod-fv } A \ B \ (x, y) = \text{prod-fv } (p \cdot A) \ (p \cdot B) \ (p \cdot x, p \cdot y)$ 
  unfolding prod-fv.simps
  by (perm-simp) (rule refl)

```

```

lemma prod-fv-supp:
  shows  $\text{prod-fv } \text{supp } \text{supp} = \text{supp}$ 
  by (rule ext)
  (auto simp: supp-Pair)

```

```

lemma prod-alpha-eq:
  shows  $\text{prod-alpha } ((=)) \ ((=)) = ((=))$ 
  unfolding prod-alpha-def
  by (auto intro!: ext)

```

```

end
theory Nominal2-FCB
imports Nominal2-Abs
begin

```

A tactic which solves all trivial cases in function definitions, and leaves the others unchanged.

```

ML <
val all-trivials : (Proof.context -> Proof.method) context-parser =
Scan.succeed (fn ctxt =>
  let
    val tac = TRYALL (SOLVED' (full-simp-tac ctxt))
  in
    Method.SIMPLE-METHOD' (K tac)
  end)
>

```

```

method-setup all-trivials = <all-trivials> <solves trivial goals>

```

lemma *Abs-lst1-fcb*:

fixes $x\ y :: 'a :: at$

and $S\ T :: 'b :: fs$

assumes $e: [[atom\ x]]lst. T = [[atom\ y]]lst. S$

and $f1: \llbracket x \neq y; atom\ y \# T; atom\ x \# (y \leftrightarrow x) \cdot T \rrbracket \Longrightarrow atom\ x \# f\ x\ T$

and $f2: \llbracket x \neq y; atom\ y \# T; atom\ x \# (y \leftrightarrow x) \cdot T \rrbracket \Longrightarrow atom\ y \# f\ x\ T$

and $p: \llbracket S = (x \leftrightarrow y) \cdot T; x \neq y; atom\ y \# T; atom\ x \# S \rrbracket$

$\Longrightarrow (x \leftrightarrow y) \cdot (f\ x\ T) = f\ y\ S$

shows $f\ x\ T = f\ y\ S$

using e

apply(*case-tac* $atom\ x \# S$)

apply(*simp* *add*: *Abs1-eq-iff'*)

apply(*elim* *conjE* *disjE*)

apply(*simp*)

apply(*rule* *trans*)

apply(*rule-tac* $p=(x \leftrightarrow y)$ **in** *supp-perm-eq[symmetric]*)

apply(*rule* *fresh-star-supp-conv*)

apply(*simp* *add*: *flip-def* *supp-swap* *fresh-star-def* $f1\ f2$)

apply(*simp* *add*: *flip-commute* p)

apply(*simp* *add*: *Abs1-eq-iff*)

done

lemma *Abs-lst-fcb*:

fixes $xs\ ys :: 'a :: fs$

and $S\ T :: 'b :: fs$

assumes $e: (Abs-lst\ (ba\ xs)\ T) = (Abs-lst\ (ba\ ys)\ S)$

and $f1: \bigwedge x. x \in set\ (ba\ xs) \Longrightarrow x \# f\ xs\ T$

and $f2: \bigwedge x. \llbracket supp\ T - set\ (ba\ xs) = supp\ S - set\ (ba\ ys); x \in set\ (ba\ ys) \rrbracket$
 $\Longrightarrow x \# f\ xs\ T$

and $eqv: \bigwedge p. \llbracket p \cdot T = S; p \cdot ba\ xs = ba\ ys; supp\ p \subseteq set\ (ba\ xs) \cup set\ (ba\ ys) \rrbracket$

$\Longrightarrow p \cdot (f\ xs\ T) = f\ ys\ S$

shows $f\ xs\ T = f\ ys\ S$

using e **apply** $-$

apply(*subst* (*asm*) *Abs-eq-iff2*)

apply(*simp* *add*: *alphas*)

apply(*elim* *exE* *conjE*)

apply(*rule* *trans*)

apply(*rule-tac* $p=p$ **in** *supp-perm-eq[symmetric]*)

apply(*rule* *fresh-star-supp-conv*)

apply(*drule* *fresh-star-perm-set-conv*)

apply(*rule* *finite-Diff*)

apply(*rule* *finite-supp*)

apply(*subgoal-tac* ($set\ (ba\ xs) \cup set\ (ba\ ys)$) $\#* f\ xs\ T$)

apply(*metis* *Un-absorb2* *fresh-star-Un*)

apply(*subst* *fresh-star-Un*)

apply(*rule* *conjI*)

apply(*simp* *add*: *fresh-star-def* $f1$)

apply(*simp* *add*: *fresh-star-def* $f2$)

apply(*simp* *add*: *eqv*)

done

lemma *Abs-set-fcb*:

fixes $xs\ ys :: 'a :: fs$
and $S\ T :: 'b :: fs$
assumes $e: (Abs-set\ (ba\ xs)\ T) = (Abs-set\ (ba\ ys)\ S)$
and $f1: \bigwedge x. x \in ba\ xs \implies x \# f\ xs\ T$
and $f2: \bigwedge x. \llbracket supp\ T - ba\ xs = supp\ S - ba\ ys; x \in ba\ ys \rrbracket \implies x \# f\ xs\ T$
and $eqv: \bigwedge p. \llbracket p \cdot T = S; p \cdot ba\ xs = ba\ ys; supp\ p \subseteq ba\ xs \cup ba\ ys \rrbracket \implies p \cdot (f\ xs\ T) = f\ ys\ S$
shows $f\ xs\ T = f\ ys\ S$
using e apply –
apply(subst (asm) Abs-eq-iff2)
apply(simp add: alphas)
apply(elim exE conjE)
apply(rule trans)
apply(rule-tac $p=p$ in supp-perm-eq[symmetric])
apply(rule fresh-star-supp-conv)
apply(drule fresh-star-perm-set-conv)
apply(rule finite-Diff)
apply(rule finite-supp)
apply(subgoal-tac $(ba\ xs \cup ba\ ys) \#* f\ xs\ T$)
apply(metis Un-absorb2 fresh-star-Un)
apply(subst fresh-star-Un)
apply(rule conjI)
apply(simp add: fresh-star-def f1)
apply(simp add: fresh-star-def f2)
apply(simp add: eqv)
done

lemma *Abs-res-fcb*:

fixes $xs\ ys :: ('a :: at-base)\ set$
and $S\ T :: 'b :: fs$
assumes $e: (Abs-res\ (atom\ 'xs)\ T) = (Abs-res\ (atom\ 'ys)\ S)$
and $f1: \bigwedge x. x \in atom\ 'xs \implies x \in supp\ T \implies x \# f\ xs\ T$
and $f2: \bigwedge x. \llbracket supp\ T - atom\ 'xs = supp\ S - atom\ 'ys; x \in atom\ 'ys; x \in supp\ S \rrbracket \implies x \# f\ xs\ T$
and $eqv: \bigwedge p. \llbracket p \cdot T = S; supp\ p \subseteq atom\ 'xs \cap supp\ T \cup atom\ 'ys \cap supp\ S; p \cdot (atom\ 'xs \cap supp\ T) = atom\ 'ys \cap supp\ S \rrbracket \implies p \cdot (f\ xs\ T) = f\ ys\ S$
shows $f\ xs\ T = f\ ys\ S$
using e apply –
apply(subst (asm) Abs-eq-res-set)
apply(subst (asm) Abs-eq-iff2)
apply(simp add: alphas)
apply(elim exE conjE)
apply(rule trans)
apply(rule-tac $p=p$ in supp-perm-eq[symmetric])
apply(rule fresh-star-supp-conv)
apply(drule fresh-star-perm-set-conv)

```

apply(rule finite-Diff)
apply(rule finite-supp)
apply(subgoal-tac (atom ' xs  $\cap$  supp T  $\cup$  atom ' ys  $\cap$  supp S)  $\#^*$  f xs T)
apply(metis Un-absorb2 fresh-star-Un)
apply(subst fresh-star-Un)
apply(rule conjI)
apply(simp add: fresh-star-def f1)
apply(subgoal-tac supp T - atom ' xs = supp S - atom ' ys)
apply(simp add: fresh-star-def f2)
apply(blast)
apply(simp add: eqv)
done

```

lemma Abs-set-fcb2:

```

fixes as bs :: atom set
  and x y :: 'b :: fs
  and c::'c::fs
assumes eq: [as]set. x = [bs]set. y
and fin: finite as finite bs
and fcb1: as  $\#^*$  f as x c
and fresh1: as  $\#^*$  c
and fresh2: bs  $\#^*$  c
and perm1:  $\bigwedge p. \text{supp } p \#^* c \implies p \cdot (f \text{ as } x \text{ c}) = f (p \cdot \text{as}) (p \cdot x) \text{ c}$ 
and perm2:  $\bigwedge p. \text{supp } p \#^* c \implies p \cdot (f \text{ bs } y \text{ c}) = f (p \cdot \text{bs}) (p \cdot y) \text{ c}$ 
shows f as x c = f bs y c
proof -
  have supp (as, x, c) supports (f as x c)
    unfolding supports-def fresh-def[symmetric]
    by (simp add: fresh-Pair perm1 fresh-star-def supp-swap swap-fresh-fresh)
  then have fin1: finite (supp (f as x c))
    using fin by (auto intro: supports-finite simp add: finite-supp supp-of-finite-sets
supp-Pair)
  have supp (bs, y, c) supports (f bs y c)
    unfolding supports-def fresh-def[symmetric]
    by (simp add: fresh-Pair perm2 fresh-star-def supp-swap swap-fresh-fresh)
  then have fin2: finite (supp (f bs y c))
    using fin by (auto intro: supports-finite simp add: finite-supp supp-of-finite-sets
supp-Pair)
  obtain q::perm where
    fr1: (q  $\cdot$  as)  $\#^*$  (x, c, f as x c, f bs y c) and
    fr2: supp q  $\#^*$  ([as]set. x) and
    inc: supp q  $\subseteq$  as  $\cup$  (q  $\cdot$  as)
    using at-set-avoiding3[where xs=as and c=(x, c, f as x c, f bs y c) and
x=[as]set. x]
    fin1 fin2 fin
  by (auto simp add: supp-Pair finite-supp Abs-fresh-star dest: fresh-star-supp-conv)
  have [q  $\cdot$  as]set. (q  $\cdot$  x) = q  $\cdot$  ([as]set. x) by simp

```

```

also have ... = [as]set. x
  by (simp only: fr2 perm-supp-eq)
finally have [q · as]set. (q · x) = [bs]set. y using eq by simp
then obtain r::perm where
  qq1: q · x = r · y and
  qq2: q · as = r · bs and
  qq3: supp r ⊆ (q · as) ∪ bs
  apply(drule-tac sym)
  apply(simp only: Abs-eq-iff2 alphas)
  apply(erule exE)
  apply(erule conjE)+
  apply(drule-tac x=p in meta-spec)
  apply(simp add: set-eqvt)
  apply(blast)
  done
have as #* f as x c by (rule fcb1)
then have q · (as #* f as x c)
  by (simp add: permute-bool-def)
then have (q · as) #* f (q · as) (q · x) c
  apply(simp only: fresh-star-eqvt set-eqvt)
  apply(subst (asm) perm1)
  using inc fresh1 fr1
  apply(auto simp add: fresh-star-def fresh-Pair)
  done
then have (r · bs) #* f (r · bs) (r · y) c using qq1 qq2 by simp
then have r · (bs #* f bs y c)
  apply(simp only: fresh-star-eqvt set-eqvt)
  apply(subst (asm) perm2[symmetric])
  using qq3 fresh2 fr1
  apply(auto simp add: set-eqvt fresh-star-def fresh-Pair)
  done
then have fcb2: bs #* f bs y c by (simp add: permute-bool-def)
have f as x c = q · (f as x c)
  apply(rule perm-supp-eq[symmetric])
  using inc fcb1 fr1 by (auto simp add: fresh-star-def)
also have ... = f (q · as) (q · x) c
  apply(rule perm1)
  using inc fresh1 fr1 by (auto simp add: fresh-star-def)
also have ... = f (r · bs) (r · y) c using qq1 qq2 by simp
also have ... = r · (f bs y c)
  apply(rule perm2[symmetric])
  using qq3 fresh2 fr1 by (auto simp add: fresh-star-def)
also have ... = f bs y c
  apply(rule perm-supp-eq)
  using qq3 fr1 fcb2 by (auto simp add: fresh-star-def)
finally show ?thesis by simp
qed

```

```

lemma Abs-res-fcb2:
  fixes as bs :: atom set
    and x y :: 'b :: fs
    and c::'c::fs
  assumes eq: [as]res. x = [bs]res. y
  and fin: finite as finite bs
  and fcb1: (as ∩ supp x) #* f (as ∩ supp x) x c
  and fresh1: as #* c
  and fresh2: bs #* c
  and perm1:  $\bigwedge p. \text{supp } p \#* c \implies p \cdot (f (as \cap \text{supp } x) x c) = f (p \cdot (as \cap \text{supp } x)) (p \cdot x) c$ 
  and perm2:  $\bigwedge p. \text{supp } p \#* c \implies p \cdot (f (bs \cap \text{supp } y) y c) = f (p \cdot (bs \cap \text{supp } y)) (p \cdot y) c$ 
  shows  $f (as \cap \text{supp } x) x c = f (bs \cap \text{supp } y) y c$ 
proof –
  have supp (as, x, c) supports (f (as ∩ supp x) x c)
    unfolding supports-def fresh-def[symmetric]
    by (simp add: fresh-Pair perm1 fresh-star-def supp-swap swap-fresh-fresh inter-eqvt supp-eqvt)
  then have fin1: finite (supp (f (as ∩ supp x) x c))
    using fin by (auto intro: supports-finite simp add: finite-supp supp-of-finite-sets supp-Pair)
  have supp (bs, y, c) supports (f (bs ∩ supp y) y c)
    unfolding supports-def fresh-def[symmetric]
    by (simp add: fresh-Pair perm2 fresh-star-def supp-swap swap-fresh-fresh inter-eqvt supp-eqvt)
  then have fin2: finite (supp (f (bs ∩ supp y) y c))
    using fin by (auto intro: supports-finite simp add: finite-supp supp-of-finite-sets supp-Pair)
  obtain q::perm where
    fr1: (q ∙ (as ∩ supp x)) #* (x, c, f (as ∩ supp x) x c, f (bs ∩ supp y) y c) and
    fr2: supp q #* ([as ∩ supp x]set. x) and
    inc: supp q ⊆ (as ∩ supp x) ∪ (q ∙ (as ∩ supp x))
    using at-set-avoiding3 [where xs=as ∩ supp x and c=(x, c, f (as ∩ supp x) x c, f (bs ∩ supp y) y c)
      and x=[as ∩ supp x]set. x]
      fin1 fin2 fin
  apply (auto simp add: supp-Pair finite-supp Abs-fresh-star dest: fresh-star-supp-conv)
  done
  have [q ∙ (as ∩ supp x)]set. (q ∙ x) = q ∙ ([as ∩ supp x]set. x) by simp
  also have ... = [as ∩ supp x]set. x
    by (simp only: fr2 perm-supp-eq)
  finally have [q ∙ (as ∩ supp x)]set. (q ∙ x) = [bs ∩ supp y]set. y using eq
    by(simp add: Abs-eq-res-set)
  then obtain r::perm where
    qq1: q ∙ x = r ∙ y and
    qq2: (q ∙ as ∩ supp (q ∙ x)) = r ∙ (bs ∩ supp y) and
    qq3: supp r ⊆ (bs ∩ supp y) ∪ q ∙ (as ∩ supp x)
    apply(drule-tac sym)

```

```

apply(simp only: Abs-eq-iff2 alphas)
apply(erule exE)
apply(erule conjE)+
apply(drule-tac x=p in meta-spec)
apply(simp add: set-eqvt inter-eqvt supp-eqvt)
done
have ( $as \cap \text{supp } x$ )  $\#* f$  ( $as \cap \text{supp } x$ )  $x$   $c$  by (rule fcb1)
then have  $q \cdot ((as \cap \text{supp } x) \#* f (as \cap \text{supp } x) x c)$ 
  by (simp add: permute-bool-def)
then have ( $q \cdot (as \cap \text{supp } x)$ )  $\#* f$  ( $q \cdot (as \cap \text{supp } x)$ ) ( $q \cdot x$ )  $c$ 
  apply(simp only: fresh-star-eqvt set-eqvt)
  apply(subst (asm) perm1)
  using inc fresh1 fr1
  apply(auto simp add: fresh-star-def fresh-Pair)
  done
then have ( $r \cdot (bs \cap \text{supp } y)$ )  $\#* f$  ( $r \cdot (bs \cap \text{supp } y)$ ) ( $r \cdot y$ )  $c$  using qq1 qq2
  apply(perm-simp)
  apply simp
  done
then have  $r \cdot ((bs \cap \text{supp } y) \#* f (bs \cap \text{supp } y) y c)$ 
  apply(simp only: fresh-star-eqvt set-eqvt)
  apply(subst (asm) perm2[symmetric])
  using qq3 fresh2 fr1
  apply(auto simp add: set-eqvt fresh-star-def fresh-Pair)
  done
then have fc2: ( $bs \cap \text{supp } y$ )  $\#* f$  ( $bs \cap \text{supp } y$ )  $y$   $c$  by (simp add: permute-bool-def)
have  $f (as \cap \text{supp } x) x c = q \cdot (f (as \cap \text{supp } x) x c)$ 
  apply(rule perm-supp-eq[symmetric])
  using inc fcb1 fr1
  apply (auto simp add: fresh-star-def)
  done
also have  $\dots = f (q \cdot (as \cap \text{supp } x)) (q \cdot x) c$ 
  apply(rule perm1)
  using inc fresh1 fr1 by (auto simp add: fresh-star-def)
also have  $\dots = f (r \cdot (bs \cap \text{supp } y)) (r \cdot y) c$  using qq1 qq2
  apply(perm-simp)
  apply simp
  done
also have  $\dots = r \cdot (f (bs \cap \text{supp } y) y c)$ 
  apply(rule perm2[symmetric])
  using qq3 fresh2 fr1 by (auto simp add: fresh-star-def)
also have  $\dots = f (bs \cap \text{supp } y) y c$ 
  apply(rule perm-supp-eq)
  using qq3 fr1 fcb2 by (auto simp add: fresh-star-def)
finally show ?thesis by simp
qed

```

lemma *Abs-lst-fcb2*:

```

fixes as bs :: atom list
  and x y :: 'b :: fs
  and c::'c::fs
assumes eq: [as]lst. x = [bs]lst. y
and fc1: (set as) #* f as x c
and fresh1: set as #* c
and fresh2: set bs #* c
and perm1:  $\bigwedge p. \text{supp } p \#* c \implies p \cdot (f \text{ as } x \ c) = f (p \cdot \text{as}) (p \cdot x) \ c$ 
and perm2:  $\bigwedge p. \text{supp } p \#* c \implies p \cdot (f \text{ bs } y \ c) = f (p \cdot \text{bs}) (p \cdot y) \ c$ 
shows f as x c = f bs y c
proof –
  have supp (as, x, c) supports (f as x c)
    unfolding supports-def fresh-def[symmetric]
    by (simp add: fresh-Pair perm1 fresh-star-def supp-swap swap-fresh-fresh)
  then have fin1: finite (supp (f as x c))
    by (auto intro: supports-finite simp add: finite-supp)
  have supp (bs, y, c) supports (f bs y c)
    unfolding supports-def fresh-def[symmetric]
    by (simp add: fresh-Pair perm2 fresh-star-def supp-swap swap-fresh-fresh)
  then have fin2: finite (supp (f bs y c))
    by (auto intro: supports-finite simp add: finite-supp)
  obtain q::perm where
    fr1: (q · (set as)) #* (x, c, f as x c, f bs y c) and
    fr2: supp q #* Abs-lst as x and
    inc: supp q  $\subseteq$  (set as)  $\cup$  q · (set as)
    using at-set-avoiding3[where xs=set as and c=(x, c, f as x c, f bs y c) and
x=[as]lst. x]
    fin1 fin2
    by (auto simp add: supp-Pair finite-supp Abs-fresh-star dest: fresh-star-supp-conv)
  have Abs-lst (q · as) (q · x) = q · Abs-lst as x by simp
  also have ... = Abs-lst as x
    by (simp only: fr2 perm-supp-eq)
  finally have Abs-lst (q · as) (q · x) = Abs-lst bs y using eq by simp
  then obtain r::perm where
    qq1: q · x = r · y and
    qq2: q · as = r · bs and
    qq3: supp r  $\subseteq$  (q · (set as))  $\cup$  set bs
    apply (drule-tac sym)
    apply (simp only: Abs-eq-iff2 alphas)
    apply (erule exE)
    apply (erule conjE)+
    apply (drule-tac x=p in meta-spec)
    apply (simp add: set-eqvt)
    apply (blast)
    done
  have (set as) #* f as x c by (rule fc1)
  then have q · ((set as) #* f as x c)
    by (simp add: permute-bool-def)
  then have set (q · as) #* f (q · as) (q · x) c

```

```

apply(simp only: fresh-star-eqvt set-eqvt)
apply(subst (asm) perm1)
using inc fresh1 fr1
apply(auto simp add: fresh-star-def fresh-Pair)
done
then have set (r · bs) #* f (r · bs) (r · y) c using qq1 qq2 by simp
then have r · ((set bs) #* f bs y c)
apply(simp only: fresh-star-eqvt set-eqvt)
apply(subst (asm) perm2[symmetric])
using qq3 fresh2 fr1
apply(auto simp add: set-eqvt fresh-star-def fresh-Pair)
done
then have fc2: (set bs) #* f bs y c by (simp add: permute-bool-def)
have f as x c = q · (f as x c)
apply(rule perm-supp-eq[symmetric])
using inc fc1 fr1 by (auto simp add: fresh-star-def)
also have ... = f (q · as) (q · x) c
apply(rule perm1)
using inc fresh1 fr1 by (auto simp add: fresh-star-def)
also have ... = f (r · bs) (r · y) c using qq1 qq2 by simp
also have ... = r · (f bs y c)
apply(rule perm2[symmetric])
using qq3 fresh2 fr1 by (auto simp add: fresh-star-def)
also have ... = f bs y c
apply(rule perm-supp-eq)
using qq3 fr1 fc2 by (auto simp add: fresh-star-def)
finally show ?thesis by simp
qed

```

```

lemma Abs-lst1-fcb2:
fixes a b :: atom
and x y :: 'b :: fs
and c::'c :: fs
assumes e: [[a]]lst. x = [[b]]lst. y
and fc1: a #* f a x c
and fresh: {a, b} #* c
and perm1:  $\bigwedge p. \text{supp } p \#* c \implies p \cdot (f a x c) = f (p \cdot a) (p \cdot x) c$ 
and perm2:  $\bigwedge p. \text{supp } p \#* c \implies p \cdot (f b y c) = f (p \cdot b) (p \cdot y) c$ 
shows f a x c = f b y c
using e
apply(drule-tac Abs-lst-fcb2[where c=c and f= $\lambda(as::atom list) . f (hd as)$ ])
apply(simp-all)
using fc1 fresh perm1 perm2
apply(simp-all add: fresh-star-def)
done

```

```

lemma Abs-lst1-fcb2':
fixes a b :: 'a::at-base
and x y :: 'b :: fs

```

```

    and c::'c :: fs
  assumes e: [[atom a]]lst. x = [[atom b]]lst. y
  and fcb1: atom a # f a x c
  and fresh: {atom a, atom b} #* c
  and perm1:  $\bigwedge p. \text{supp } p \#* c \implies p \cdot (f a x c) = f (p \cdot a) (p \cdot x) c$ 
  and perm2:  $\bigwedge p. \text{supp } p \#* c \implies p \cdot (f b y c) = f (p \cdot b) (p \cdot y) c$ 
  shows f a x c = f b y c
using e
apply(drule-tac Abs-lst1-fcb2[where c=c and f= $\lambda a . f ((inv \text{atom}) a)$ ])
using fcb1 fresh perm1 perm2
apply(simp-all add: fresh-star-def inv-f-f inj-on-def atom-eqvt)
done

end
theory Nominal2
imports
  Nominal2-Base Nominal2-Abs Nominal2-FCB
keywords
  nominal-datatype :: thy-defn and
  nominal-function nominal-inductive nominal-termination :: thy-goal-defn and
  avoids binds
begin

ML-file <nominal-dt-data.ML>
ML <open Nominal-Dt-Data>

ML-file <nominal-dt-rawfuns.ML>
ML <open Nominal-Dt-RawFuns>

ML-file <nominal-dt-alpha.ML>
ML <open Nominal-Dt-Alpha>

ML-file <nominal-dt-quot.ML>
ML <open Nominal-Dt-Quot>

ML-file <nominal-induct.ML>
method-setup nominal-induct =
  <NominalInduct.nominal-induct-method>
  <nominal induction>

ML-file <nominal-inductive.ML>

```



```

ML-file <nominal-function-common.ML>
ML-file <nominal-function-core.ML>
ML-file <nominal-mutual.ML>
ML-file <nominal-function.ML>
ML-file <nominal-termination.ML>

```

```

ML <
  val eqvt-attr = Attrib.internal (K Nominal-ThmDecls.eqvt-add)
  val simp-attr = Attrib.internal (K Simplifier.simp-add)
  val induct-attr = Attrib.internal (K Induct.induct-simp-add)
>

```

34 Interface for *nominal-datatype*

```

ML <
  fun get-cnstrs dts =
    map snd dts

  fun get-typed-cnstrs dts =
    flat (map (fn ((bn, -, -), constrs) =>
      (map (fn (bn', -, -) => (Binding.name-of bn, Binding.name-of bn')) constrs))
    dts)

  fun get-cnstr-strs dts =
    map (fn (bn, -, -) => Binding.name-of bn) (flat (get-cnstrs dts))

  fun get-bn-fun-strs bn-funs =
    map (fn (bn-fun, -, -) => Binding.name-of bn-fun) bn-funs
>

```

Infrastructure for adding *-raw* to types and terms

```

ML <
  fun add-raw s = s ^ -raw
  fun add-raws ss = map add-raw ss
  fun raw-bind bn = Binding.suffix-name -raw bn

  fun replace-str ss s =
    case (AList.lookup (op =) ss s) of
      SOME s' => s'
    | NONE => s

  fun replace-typ ty-ss (Type (a, Ts)) = Type (replace-str ty-ss a, map (replace-typ
  ty-ss) Ts)
    | replace-typ ty-ss T = T

  fun raw-dts ty-ss dts =
  let
    fun raw-dts-aux1 (bind, tys, -) =

```

```

    (raw-bind bind, map (replace-typ ty-ss) tys, NoSyn)

  fun raw-dts-aux2 ((bind, ty-args, -), constra) =
    ((raw-bind bind, ty-args, NoSyn), map raw-dts-aux1 constra)
  in
    map raw-dts-aux2 dts
  end

  fun replace-aterm trm-ss (Const (a, T)) = Const (replace-str trm-ss a, T)
    | replace-aterm trm-ss (Free (a, T)) = Free (replace-str trm-ss a, T)
    | replace-aterm trm-ss trm = trm

  fun replace-term trm-ss ty-ss trm =
    trm |> Term.map-aterms (replace-aterm trm-ss) |> map-types (replace-typ ty-ss)
  >

  ML <
  fun rawify-dts dts dts-env = raw-dts dts-env dts
  >

  ML <
  fun rawify-bn-funs dts-env cnstra-env bn-fun-env bn-funs bn-egs =
    let
      val bn-funs' = map (fn (bn, ty, -) =>
        (raw-bind bn, SOME (replace-typ dts-env ty), NoSyn)) bn-funs

      val bn-egs' = map (fn (attr, trm) =>
        ((attr, replace-term (cnstra-env @ bn-fun-env) dts-env trm), [], [])) bn-egs
    in
      (bn-funs', bn-egs')
    end
  >

  ML <
  fun rawify-bclauses dts-env cnstra-env bn-fun-env bclauses =
    let
      fun rawify-bnds bnds =
        map (apfst (Option.map (replace-term (cnstra-env @ bn-fun-env) dts-env)))
          bnds

      fun rawify-bclause (BC (mode, bnds, bdys)) = BC (mode, rawify-bnds bnds, bdys)
    in
      (map o map o map) rawify-bclause bclauses
    end
  >

  ML <
  (* definition of the raw datatype *)

```

```

fun define-raw-dts dts cnstr-names cnstr-tys bn-funs bn-egs bclauses lthy =
let
  val thy = Local-Theory.exit-global lthy
  val thy-name = Context.theory-name thy

  val dt-names = map (fn ((s, -, -), -) => Binding.name-of s) dts
  val dt-full-names = map (Long-Name.qualify thy-name) dt-names
  val dt-full-names' = add-rows dt-full-names
  val dts-env = dt-full-names ~~ dt-full-names'

  val cnstr-full-names = map (Long-Name.qualify thy-name) cnstr-names
  val cnstr-full-names' = map (fn (x, y) => Long-Name.qualify thy-name
    (Long-Name.qualify (add-row x) (add-row y))) cnstr-tys
  val cnstrs-env = cnstr-full-names ~~ cnstr-full-names'

  val bn-fun-strings = get-bn-fun-strings bn-funs
  val bn-fun-strings' = add-rows bn-fun-strings
  val bn-fun-env = bn-fun-strings ~~ bn-fun-strings'
  val bn-fun-full-env = map (apply2 (Long-Name.qualify thy-name))
    (bn-fun-strings ~~ bn-fun-strings')

  val raw-dts = rawify-dts dts dts-env
  val (raw-bn-funs, raw-bn-egs) = rawify-bn-funs dts-env cnstrs-env bn-fun-env
  val raw-bclauses = rawify-bclauses dts-env cnstrs-env bn-fun-full-env bclauses

  val (raw-full-dt-names', thy1) =
    BNF-LFP-Compat.add-datatype [BNF-LFP-Compat.Kill-Type-Args] raw-dts thy

  val lthy1 = Named-Target.theory-init thy1

  val dtinfos = map (Old-Datatype-Data.the-info (Proof-Context.theory-of lthy1))
  raw-full-dt-names'
  val raw-fp-sugars = map (the o BNF-FP-Def-Sugar.fp-sugar-of lthy1) raw-full-dt-names'
  val {descr, ...} = hd dtinfos

  val raw-ty-args = hd (Old-Datatype-Aux.get-rec-types descr)
    |> snd o dest-Type
    |> map dest-TFree
  val raw-schematic-ty-args = (snd o dest-Type o #T o hd) raw-fp-sugars
  val typ-subst = raw-schematic-ty-args ~~ map TFree raw-ty-args
  val freezeT = Term.typ-subst-atomic typ-subst
  val freeze = Term.subst-atomic-types typ-subst
  val raw-tys = map (freezeT o #T) raw-fp-sugars

  val raw-cns-info = all-dtyp-constrs-types descr
  val raw-all-cns = map (map freeze o #ctrs o #ctr-sugar o #fp-ctr-sugar) raw-fp-sugars

```

```

    val raw-inject-thms = flat (map #inject dtinfos)
    val raw-distinct-thms = flat (map #distinct dtinfos)
    val raw-induct-thm = (hd o #common-co-inducts o the o #fp-co-induct-sugar o
hd) raw-fp-sugars
    val raw-induct-thms = map (the-single o #co-inducts o the o #fp-co-induct-sugar)
raw-fp-sugars
    val raw-exhaust-thms = map #exhaust dtinfos
    val raw-size-trms = map HOLogic.size-const raw-tys
    val raw-size-thms = these (Option.map (#2 o #2)
(BNF-LFP-Size.size-of lthy1 (hd raw-full-dt-names')))

val raw-result = RawDtInfo
  {raw-dt-names = raw-full-dt-names',
   raw-fp-sugars = raw-fp-sugars,
   raw-dts = raw-dts,
   raw-tys = raw-tys,
   raw-ty-args = raw-ty-args,
   raw-cns-info = raw-cns-info,
   raw-all-cns = raw-all-cns,
   raw-inject-thms = raw-inject-thms,
   raw-distinct-thms = raw-distinct-thms,
   raw-induct-thm = raw-induct-thm,
   raw-induct-thms = raw-induct-thms,
   raw-exhaust-thms = raw-exhaust-thms,
   raw-size-trms = raw-size-trms,
   raw-size-thms = raw-size-thms}
in
  (raw-bclauses, raw-bn-funs, raw-bn-egs, raw-result, lthy1)
end
>

```

ML <

```

fun nominal-datatype2 opt-thms-name dts bn-funs bn-egs bclauses lthy =
let
  val cnstr-names = get-cnstr-strs dts
  val cnstr-tys = get-typed-cnstrs dts

  val - = trace-msg (K Defining raw datatypes...)
  val (raw-bclauses, raw-bn-funs, raw-bn-egs, raw-dt-info, lthy0) =
    define-raw-dts dts cnstr-names cnstr-tys bn-funs bn-egs bclauses lthy

  val RawDtInfo
    {raw-dt-names,
     raw-tys,
     raw-ty-args,
     raw-fp-sugars,
     raw-all-cns,
     raw-inject-thms,

```

```

raw-distinct-thms,
raw-induct-thm,
raw-induct-thms,
raw-exhaust-thms,
raw-size-trms,
raw-size-thms, ...} = raw-dt-info

val - = trace-msg (K Defining raw permutations...)
val ((raw-perm-funs, raw-perm-simps, raw-perm-laws), lthy2a) = define-raw-perms
raw-dt-info lthy0

(* noting the raw permutations as eqvt theorems *)
val lthy3 = snd (Local-Theory.note ((Binding.empty, [eqvt-attr]), raw-perm-simps)
lthy2a)

val - = trace-msg (K Defining raw fv- and bn-functions...)
val (raw-bns, raw-bn-defs, raw-bn-info, raw-bn-inducts, lthy3a) =
define-raw-bns raw-dt-info raw-bn-funs raw-bn-egs lthy3

(* defining the permute-bn functions *)
val (raw-perm-bns, raw-perm-bn-simps, lthy3b) =
define-raw-bn-perms raw-dt-info raw-bn-info lthy3a

val (raw-fvs, raw-fv-bns, raw-fv-defs, raw-fv-bns-induct, lthy3c) =
define-raw-fvs raw-dt-info raw-bn-info raw-bclauses lthy3b

val - = trace-msg (K Defining alpha relations...)
val (alpha-result, lthy4) =
define-raw-alpha raw-dt-info raw-bn-info raw-bclauses raw-fvs lthy3c

val - = trace-msg (K Proving distinct theorems...)
val alpha-distincts = raw-prove-alpha-distincts lthy4 alpha-result raw-dt-info

val - = trace-msg (K Proving eq-iff theorems...)
val alpha-eq-iff = raw-prove-alpha-eq-iff lthy4 alpha-result raw-dt-info

val - = trace-msg (K Proving equivariance of bns, fvs, size and alpha...)
val raw-bn-eqvt =
raw-prove-eqvt raw-bns raw-bn-inducts (raw-bn-defs @ raw-perm-simps) lthy4

(* noting the raw-bn-eqvt lemmas in a temporary theory *)
val lthy-tmp =
lthy4
|> Local-Theory.begin-nested
|> snd
|> Local-Theory.note ((Binding.empty, [eqvt-attr]), raw-bn-eqvt)
|> snd
|> Local-Theory.end-nested

```

```

val raw-fv-eqvt =
  raw-prove-eqvt (raw-fvs @ raw-fv-bns) raw-fv-bns-induct (raw-fv-defs @ raw-perm-simps)
    lthy-tmp

val raw-size-eqvt =
  let
    val RawDtInfo {raw-size-trms, raw-size-thms, raw-induct-thms, ...} = raw-dt-info
  in
    raw-prove-eqvt raw-size-trms raw-induct-thms (raw-size-thms @ raw-perm-simps)
      lthy-tmp
    |> map (rewrite-rule lthy-tmp
      @{thms permute-nat-def[THEN eq-reflection]})
    |> map (fn thm => thm RS @{thm sym})
  end

val lthy5 = snd (Local-Theory.note ((Binding.empty, [eqvt-attr]), raw-fv-eqvt)
  lthy-tmp)

val alpha-eqvt =
  let
    val AlphaResult {alpha-trms, alpha-bn-trms, alpha-raw-induct, alpha-intros,
  ...} = alpha-result
  in
    Nominal-Eqvt.raw-equivariance lthy5 (alpha-trms @ alpha-bn-trms) alpha-raw-induct
    alpha-intros
  end

val alpha-eqvt-norm = map (Nominal-ThmDecls.eqvt-transform lthy5) alpha-eqvt

val - = trace-msg (K Proving equivalence of alpha...)
val alpha-refl-thms = raw-prove-refl lthy5 alpha-result raw-induct-thm
val alpha-sym-thms = raw-prove-sym lthy5 alpha-result alpha-eqvt-norm
val alpha-trans-thms =
  raw-prove-trans lthy5 alpha-result (raw-distinct-thms @ raw-inject-thms) al-
  pha-eqvt-norm

val (alpha-equivp-thms, alpha-bn-equivp-thms) =
  raw-prove-equivp lthy5 alpha-result alpha-refl-thms alpha-sym-thms alpha-trans-thms

val - = trace-msg (K Proving alpha implies bn...)
val alpha-bn-imp-thms = raw-prove-bn-imp lthy5 alpha-result

val - = trace-msg (K Proving respectfulness...)
val raw-funs-rsp-aux =
  raw-fv-bn-rsp-aux lthy5 alpha-result raw-fvs raw-bns raw-fv-bns (raw-bn-defs @
  raw-fv-defs)

val raw-funs-rsp = map (Drule.eta-contraction-rule o mk-funs-rsp lthy5) raw-funs-rsp-aux

```

```

fun match-const cnst th =
  (fst o dest-Const o snd o dest-comb o HOLogic.dest-Trueprop o Thm.prop-of)
th =
  fst (dest-Const cnst);
fun find-matching-rsp cnst =
  hd (filter (fn th => match-const cnst th) raw-funs-rsp);
val raw-fv-rsp = map find-matching-rsp raw-fvs;
val raw-bn-rsp = map find-matching-rsp raw-bns;
val raw-fv-bn-rsp = map find-matching-rsp raw-fv-bns;

val raw-size-rsp =
  raw-size-rsp-aux lthy5 alpha-result (raw-size-thms @ raw-size-eqvt)
  |> map (mk-funs-rsp lthy5)

val raw-constrs-rsp =
  raw-constrs-rsp lthy5 alpha-result raw-all-cns (alpha-bn-imp-thms @ raw-funs-rsp-aux)

val alpha-permute-rsp = map (mk-alpha-permute-rsp lthy5) alpha-eqvt

val alpha-bn-rsp =
  raw-alpha-bn-rsp alpha-result alpha-bn-equivp-thms alpha-bn-imp-thms

val raw-perm-bn-rsp = raw-perm-bn-rsp lthy5 alpha-result raw-perm-bns raw-perm-bn-simps

val - = trace-msg (K Defining the quotient types...)
val qty-descr = map (fn ((bind, vs, mx), -) => (map fst vs, bind, mx)) dts

val (qty-infos, lthy7) =
  let
    val AlphaResult {alpha-trms, alpha-tys, ...} = alpha-result
  in
    define-qtypes qty-descr alpha-tys alpha-trms alpha-equivp-thms lthy5
  end

val qtys = map #qtyp qty-infos
val qty-full-names = map (fst o dest-Type) qtys
val qty-names = map Long-Name.base-name qty-full-names

val - = trace-msg (K Defining the quotient constants...)
val qconstrs-descrs =
  (map2 o map2) (fn (b, -, mx) => fn (t, th) => (Variable.check-name b, t, mx,
th))
  (get-cnstrs dts) (map (op ~) (raw-all-cns ~ raw-constrs-rsp))

val qbns-descr =
  map2 (fn (b, -, mx) => fn (t, th) => (Variable.check-name b, t, mx, th))
bn-funs (raw-bns ~ raw-bn-rsp)

val qfvs-descr =

```

```

    map2 (fn n => fn (t, th) => (fv- ^ n, t, NoSyn, th)) qty-names (raw-fvs ~~
raw-fv-rsp)

    val qfv-bns-descr =
      map2 (fn (b, -, -) => fn (t, th) => (fv- ^ Variable.check-name b, t, NoSyn,
th))
        bn-funs (raw-fv-bns ~~ raw-fv-bn-rsp)

    val qalpha-bns-descr =
      let
        val AlphaResult {alpha-bn-trms, ...} = alpha-result
      in
        map2 (fn (b, -, -) => fn (t, th) => (alpha- ^ Variable.check-name b, t, NoSyn,
th))
          bn-funs (alpha-bn-trms ~~ alpha-bn-rsp)
        end

    val qperm-descr =
      map2 (fn n => fn (t, th) => (permute- ^ n, Type.legacy-freeze t, NoSyn, th))
        qty-names (raw-perm-funs ~~ (take (length raw-perm-funs) alpha-permute-rsp))

    val qsize-descr =
      map2 (fn n => fn (t, th) => (size- ^ n, t, NoSyn, th)) qty-names
        (raw-size-trms ~~ (take (length raw-size-trms) raw-size-rsp))

    val qperm-bn-descr =
      map2 (fn (b, -, -) => fn (t, th) => (permute- ^ Variable.check-name b, t,
NoSyn, th))
        bn-funs (raw-perm-bns ~~ raw-perm-bn-rsp)

    val ((((((qconstrs-infos, qbns-info), qfvs-info), qfv-bns-info), qalpha-bns-info), qperm-bns-info),
lthy8) =
      lthy7
      |> fold-map (define-qconsts qtys) qconstrs-descrs
      ||>> define-qconsts qtys qbns-descr
      ||>> define-qconsts qtys qfvs-descr
      ||>> define-qconsts qtys qfv-bns-descr
      ||>> define-qconsts qtys qalpha-bns-descr
      ||>> define-qconsts qtys qperm-bn-descr

    val lthy9 =
      define-qperms qtys qty-full-names raw-ty-args qperm-descr raw-perm-laws lthy8

    val lthy9a =
      define-qsizes qtys qty-full-names raw-ty-args qsize-descr lthy9

    val qtrms = (map o map) #qconst qconstrs-infos
    val qbns = map #qconst qbns-info
    val qfvs = map #qconst qfvs-info

```



```

val qfv-bns = map #qconst qfv-bns-info
val qalpha-bns = map #qconst qalpha-bns-info
val qperm-bns = map #qconst qperm-bns-info

val - = trace-msg (K Lifting of theorems...)
val eq-iff-simps = @{thms alphas permute-prod.simps prod-fv.simps prod-alpha-def
rel-prod-sel
  prod.case}

val ([ qdistincts, qeq-iffs, qfv-defs, qbn-defs, qperm-simps, qfv-qbn-equts,
      qbn-inducts, qsize-eqvt, [qinduct], qexhausts, qsize-simps, qperm-bn-simps,
      qalpha-refl-thms, qalpha-sym-thms, qalpha-trans-thms ], lthyB) =
  lthy9a
|>>> lift-thms qtys [] alpha-distincts
|>>> lift-thms qtys eq-iff-simps alpha-eq-iff
|>>> lift-thms qtys [] raw-fv-defs
|>>> lift-thms qtys [] raw-bn-defs
|>>> lift-thms qtys [] raw-perm-simps
|>>> lift-thms qtys [] (raw-fv-eqvt @ raw-bn-eqvt)
|>>> lift-thms qtys [] raw-bn-inducts
|>>> lift-thms qtys [] raw-size-eqvt
|>>> lift-thms qtys [] [raw-induct-thm]
|>>> lift-thms qtys [] raw-exhaust-thms
|>>> lift-thms qtys [] raw-size-thms
|>>> lift-thms qtys [] raw-perm-bn-simps
|>>> lift-thms qtys [] alpha-refl-thms
|>>> lift-thms qtys [] alpha-sym-thms
|>>> lift-thms qtys [] alpha-trans-thms

val qinducts = Project-Rule.projections lthyB qinduct

val - = trace-msg (K Proving supp lemmas and fs-instances...)
val qsupports-thms = prove-supports lthyB qperm-simps (flat qtrms)

(* finite supp lemmas *)
val qfsupp-thms = prove-fsupp lthyB qtys qinduct qsupports-thms

(* fs instances *)
val lthyC = fs-instance qtys qty-full-names raw-ty-args qfsupp-thms lthyB

val - = trace-msg (K Proving equality between fv and supp...)
val qfv-supp-thms =
  prove-fv-supp qtys (flat qtrms) qfvs qfv-bns qalpha-bns qfv-defs qeq-iffs
  qperm-simps qfv-qbn-equts qinduct (flat raw-bclauses) lthyC
|> map Drule.eta-contraction-rule

(* postprocessing of eq and fv theorems *)
val qeq-iffs' = qeq-iffs
|> map (simplify (put-simpset HOL-basic-ss lthyC addsimps qfv-supp-thms))

```

```

|> map (simplify (put-simpset HOL-basic-ss lthyC
  addsimps @{thms prod-fv-supp prod-alpha-eq Abs-eq-iff[symmetric]}))

(* filters the theorems that are of the form qfv = supp *)
val qfv-names = map (fst o dest-Const) qfvs
fun is-qfv-thm Const-⟨Trueprop for Const-⟨HOL.eq - for ⟨Const (lhs, -)⟩ -⟩⟩ =
  member (op =) qfv-names lhs
| is-qfv-thm - = false

val qsupp-constrs = qfv-defs
|> map (simplify (put-simpset HOL-basic-ss lthyC
  addsimps (filter (is-qfv-thm o Thm.prop-of) qfv-supp-thms)))

val transform-thm = @{lemma x = y ⟹ a ∉ x ⟷ a ∉ y by simp}
val transform-thms =
  [ @{lemma a ∉ (S ∪ T) ⟷ a ∉ S ∧ a ∉ T by simp},
    @{lemma a ∉ (S - T) ⟷ a ∉ S ∨ a ∈ T by simp},
    @{lemma (lhs = (a ∉ { })) ⟷ lhs by simp},
    @{thm fresh-def[symmetric]}]

val qfresh-constrs = qsupp-constrs
|> map (fn thm => thm RS transform-thm)
|> map (simplify (put-simpset HOL-basic-ss lthyC addsimps transform-thms))

(* proving that the qbn result is finite *)
val qbn-finite-thms = prove-bns-finite qtys qbns qinduct qbn-defs lthyC

(* proving that perm-bns preserve alpha *)
val qperm-bn-alpha-thms =
  prove-perm-bn-alpha-thms qtys qperm-bns qalpha-bns qinduct qperm-bn-simps
  qeq-iffs'
  qalpha-reft-thms lthyC

(* proving the relationship of bn and permute-bn *)
val qpermute-bn-thms =
  prove-permute-bn-thms qtys qbns qperm-bns qinduct qperm-bn-simps qbn-defs
  qfv-qbn-eqvs lthyC

val - = trace-msg (K Proving strong exhaust lemmas...)
val qstrong-exhaust-thms = prove-strong-exhausts lthyC qexhausts bclauses qbn-finite-thms
  qeq-iffs'
  qfv-qbn-eqvs qpermute-bn-thms qperm-bn-alpha-thms

val - = trace-msg (K Proving strong induct lemmas...)
val qstrong-induct-thms = prove-strong-induct lthyC qinduct qstrong-exhaust-thms
  qsize-simps bclauses

(* noting the theorems *)

```

```

(* generating the prefix for the theorem names *)
val thms-name =
  the-default (Binding.name (space-implode - qty-names)) opt-thms-name
fun thms-suffix s = Binding.qualify-name true thms-name s
val case-names-attr = Attrib.internal (K (Rule-Cases.case-names cnstr-names))

val infos = mk-infos qty-full-names qeq-iffs' qdistincts qstrong-exhaust-thms qstrong-induct-thms

val (-, lthy9') = lthyC
  |> Local-Theory.declaration {syntax = false, pervasive = false} (K (fold reg-
ister-info infos))
  |> Local-Theory.note ((thms-suffix distinct, [induct-attr, simp-attr]), qdistincts)
  ||>> Local-Theory.note ((thms-suffix eq-iff, [induct-attr, simp-attr]), qeq-iffs')
  ||>> Local-Theory.note ((thms-suffix fv-defs, []), qfv-defs)
  ||>> Local-Theory.note ((thms-suffix bn-defs, []), qbn-defs)
  ||>> Local-Theory.note ((thms-suffix bn-inducts, []), qbn-inducts)
  ||>> Local-Theory.note ((thms-suffix perm-simps, [eqvt-attr, simp-attr]), qperm-simps)
  ||>> Local-Theory.note ((thms-suffix fv-bn-eqvt, [eqvt-attr]), qfv-qbn-eqvt)
  ||>> Local-Theory.note ((thms-suffix size, [simp-attr]), qsize-simps)
  ||>> Local-Theory.note ((thms-suffix size-eqvt, []), qsize-eqvt)
  ||>> Local-Theory.note ((thms-suffix induct, [case-names-attr]), [qinduct])
  ||>> Local-Theory.note ((thms-suffix inducts, [case-names-attr]), [qinducts])
  ||>> Local-Theory.note ((thms-suffix exhaust, [case-names-attr]), [qexhausts])
  ||>> Local-Theory.note ((thms-suffix strong-exhaust, [case-names-attr]), [qstrong-exhaust-thms])
  ||>> Local-Theory.note ((thms-suffix strong-induct, [case-names-attr]), [qstrong-induct-thms])
  ||>> Local-Theory.note ((thms-suffix supports, []), [qsupports-thms])
  ||>> Local-Theory.note ((thms-suffix fsupp, []), [qfsupp-thms])
  ||>> Local-Theory.note ((thms-suffix supp, []), [qsupp-constrs])
  ||>> Local-Theory.note ((thms-suffix fresh, [simp-attr]), [qfresh-constrs])
  ||>> Local-Theory.note ((thms-suffix perm-bn-simps, []), [qperm-bn-simps])
  ||>> Local-Theory.note ((thms-suffix bn-finite, []), [qbn-finite-thms])
  ||>> Local-Theory.note ((thms-suffix perm-bn-alpha, []), [qperm-bn-alpha-thms])
  ||>> Local-Theory.note ((thms-suffix permute-bn, []), [qpermute-bn-thms])
  ||>> Local-Theory.note ((thms-suffix alpha-refl, []), [qalpha-refl-thms])
  ||>> Local-Theory.note ((thms-suffix alpha-sym, []), [qalpha-sym-thms])
  ||>> Local-Theory.note ((thms-suffix alpha-trans, []), [qalpha-trans-thms])

in
  lthy9'
end
>

```

35 Preparing and parsing of the specification

```

ML <
(* adds the default sort @{sort fs} to nominal specifications *)

fun augment-sort thy S = Sign.inter-sort thy (@{sort fs}, S)

```

```

fun augment-sort-typ thy =
  map-type-tfree (fn (s, S) => TFree (s, augment-sort thy S))
>

```

ML ‹

(* generates the parsed datatypes and declares the constructors *)

```

fun prepare-dts dt-strs thy =
  let
    fun prep-spec ((tname, tys, mx), condrs) =
      ((tname, tys, mx), condrs |> map (fn (c, atys, mx', -) => (c, map snd atys,
mx')))

```

```

  val (dts, spec-ctxt) =
    Old-Datatype.read-specs (map prep-spec dt-strs) thy

```

```

  fun augment ((tname, tys, mx), condrs) =
    ((tname, map (apsnd (augment-sort thy)) tys, mx),
     condrs |> map (fn (c, tys, mx') => (c, map (augment-sort-typ thy) tys,
mx')))

```

```

  val dts' = map augment dts

```

```

fun mk-constr-trms ((tname, tys, -), condrs) =
  let
    val ty = Type (Sign.full-name thy tname, map TFree tys)
  in
    map (fn (c, tys, mx) => (c, (tys ----> ty), mx)) condrs
  end

```

```

val constr-trms = flat (map mk-constr-trms dts')

```

(* FIXME: local version *)

```

(* val (-, spec-ctxt') = Proof-Context.add-fixes constr-trms spec-ctxt *)

```

```

  val thy' = Sign.add-consts constr-trms (Proof-Context.theory-of spec-ctxt)
in
  (dts', thy')
end
>

```

ML ‹

(* parsing the binding function specifications and *)

(* declaring the function constants *)

```

fun prepare-bn-funs bn-fun-strs bn-eq-strs thy =
  let

```

```

    val lthy = Named-Target.theory-init thy

```

```

    val ((bn-funs, bn-eqs), lthy') =

```

```

    Specification.read-multi-specs bn-fun-strings bn-eq-strings lthy

fun prep-bn-fun ((bn, T), mx) = (bn, T, mx)

val bn-funs' = map prep-bn-fun bn-funs

in
  (Local-Theory.exit-global lthy')
  |> Sign.add-consts bn-funs'
  |> pair (bn-funs', bn-eqs)
end
>

```

associates every SOME with the index in the list; drops NONES

```

ML <
fun indexify xs =
  let
    fun mapp - [] = []
      | mapp i (NONE :: xs) = mapp (i + 1) xs
      | mapp i (SOME x :: xs) = (x, i) :: mapp (i + 1) xs
  in
    mapp 0 xs
  end

fun index-lookup xs x =
  case AList.lookup (op =) xs x of
    SOME x => x
  | NONE => error (Cannot find ^x^ as argument annotation.);
>

```

```

ML <
fun prepare-bclauses dt-strings thy =
  let
    val annos-bclauses =
      get-cnstrings dt-strings
      |> (map o map) (fn (-, antys, -, bns) => (map fst antys, bns))

    fun prep-binder env bn-str =
      case (Syntax.read-term-global thy bn-str) of
        Free (x, _) => (NONE, index-lookup env x)
      | Const (a, T) $ Free (x, _) => (SOME (Const (a, T)), index-lookup env x)
      | - => error (The term ^bn-str^ is not allowed as binding function.)

    fun prep-body env bn-str = index-lookup env bn-str

    fun prep-bclause env (mode, binders, bodies) =
      let
        val binders' = map (prep-binder env) binders
        val bodies' = map (prep-body env) bodies
      end
  in
    prep-bclauses thy
  end

```

```

in
  BC (mode, binders', bodies')
end

fun prep-bclauses (annos, bclause-strs) =
let
  val env = indexify annos (* for every label, associate the index *)
in
  map (prep-bclause env) bclause-strs
end
in
  ((map o map) prep-bclauses annos-bclauses, thy)
end
>

```

adds an empty binding clause for every argument that is not already part of a binding clause

```

ML <
fun included i bcs =
let
  fun incl (BC (-, bns, bds)) =
    member (op =) (map snd bns) i orelse member (op =) bds i
in
  exists incl bcs
end
>

```

```

ML <
fun complete dt-strs bclauses =
let
  val args =
    get-cnstrs dt-strs
  |> (map o map) (fn (-, antys, -, -) => length antys)

  fun complt n bcs =
let
  fun add bcs i = (if included i bcs then [] else [BC (Lst, [], [i])])
in
  bcs @ (flat (map-range (add bcs) n))
end
in
  (map2 o map2) complt args bclauses
end
>

```

```

ML <
fun nominal-datatype2-cmd (opt-thms-name, dt-strs, bn-fun-strs, bn-eq-strs) lthy =
let
  (* this theory is used just for parsing *)

```

```

val thy = Proof-Context.theory-of lthy

val (((dts, (bn-funs, bn-eqs)), bclauses), -) =
  thy
  |> prepare-dts dt-stra
  ||>> prepare-bn-funs bn-fun-stra bn-eq-stra
  ||>> prepare-bclauses dt-stra

val bclauses' = complete dt-stra bclauses
in
  nominal-datatype2 opt-thms-name dts bn-funs bn-eqs bclauses' lthy
end
>

ML <
(* nominal datatype parser *)
local
  fun triple1 ((x, y), z) = (x, y, z)
  fun triple2 ((x, y), z) = (y, x, z)
  fun tuple2 (((x, y), z), u) = (x, y, u, z)
  fun tuple3 ((x, y), (z, u)) = (x, y, z, u)
in
  val opt-name = Scan.option (Parse.binding --| Args.colon)

  val anno-typ = Scan.option (Parse.name --| @ {keyword ::}) -- Parse.typ

  val bind-mode = @ {keyword binds} |--
    Scan.optional (Args.parens
      (Args.$$$ list >> K Lst || (Args.$$$ set -- Args.$$$ +) >> K Res || Args.$$$
      set >> K Set)) Lst

  val bind-clauses =
    Parse.enum , (bind-mode -- Scan.repeat1 Parse.term -- (@ {keyword in} |--
    Scan.repeat1 Parse.name) >> triple1)

  val cnstr-parser =
    Parse.binding -- Scan.repeat anno-typ -- bind-clauses -- Parse.opt-mixfix
    >> tuple2

  (* datatype parser *)
  val dt-parser =
    (Parse.type-args-constrained -- Parse.binding -- Parse.opt-mixfix >> triple2)
    --
    (@ {keyword =} |-- Parse.enum1 | cnstr-parser)

  (* binding function parser *)
  val bnfun-parser =
    Scan.optional (@ {keyword binder} |-- Parse.Spec.specification) ([], [])

```

```

(* main parser *)
val main-parser =
  opt-name -- Parse.and-list1 dt-parser -- bnfun-parser >> tuple3

end

(* Command Keyword *)
val - = Outer-Syntax.local-theory @ {command-keyword nominal-datatype}
  declaration of nominal datatypes
  (main-parser >> nominal-datatype2-cmd)
>

end

```

```

theory Atoms
imports Nominal2-Base
begin

```

36 *nat-of* is an example of a function without finite support

```

lemma not-fresh-nat-of:
  shows  $\neg a \# \text{nat-of}$ 
unfolding fresh-def supp-def
proof (clarsimp)
  assume finite {b. (a  $\rightleftharpoons$  b)  $\cdot$  nat-of  $\neq$  nat-of}
  hence finite ({a}  $\cup$  {b. (a  $\rightleftharpoons$  b)  $\cdot$  nat-of  $\neq$  nat-of})
    by simp
  then obtain b where
    b1: b  $\neq$  a and
    b2: sort-of b = sort-of a and
    b3: (a  $\rightleftharpoons$  b)  $\cdot$  nat-of = nat-of
    by (rule obtain-atom) auto
  have nat-of a = (a  $\rightleftharpoons$  b)  $\cdot$  (nat-of a) by (simp add: permute-nat-def)
  also have ... = ((a  $\rightleftharpoons$  b)  $\cdot$  nat-of) ((a  $\rightleftharpoons$  b)  $\cdot$  a) by (simp add: permute-fun-app-eq)
  also have ... = nat-of ((a  $\rightleftharpoons$  b)  $\cdot$  a) using b3 by simp
  also have ... = nat-of b using b2 by simp
  finally have nat-of a = nat-of b by simp
  with b2 have a = b by (simp add: atom-components-eq-iff)
  with b1 show False by simp
qed

```

```

lemma supp-nat-of:
  shows supp nat-of = UNIV
  using not-fresh-nat-of [unfolded fresh-def] by auto

```


37 Manual instantiation of class *at*.

```
typedef name = {a. sort-of a = Sort "name" []}  
by (rule exists-eq-simple-sort)
```

```
instantiation name :: at  
begin
```

```
definition  
   $p \cdot a = \text{Abs-name } (p \cdot \text{Rep-name } a)$ 
```

```
definition  
   $\text{atom } a = \text{Rep-name } a$ 
```

```
instance  
apply (rule at-class)  
apply (rule type-definition-name)  
apply (rule atom-name-def)  
apply (rule permute-name-def)  
done
```

```
end
```

```
lemma sort-of-atom-name:  
  shows sort-of (atom (a::name)) = Sort "name" []  
  by (simp add: atom-name-def Rep-name[simplified])
```

Custom syntax for concrete atoms of type at

```
term a::name
```

38 Automatic instantiation of class *at*.

```
atom-decl name2
```

```
lemma  
   $\text{sort-of } (\text{atom } (a::\text{name2})) \neq \text{sort-of } (\text{atom } (b::\text{name}))$   
by (simp add: sort-of-atom-name)
```

example swappings

```
lemma  
  fixes a b::atom  
  assumes sort-of a = sort-of b  
  shows ( $a \rightleftharpoons b$ )  $\cdot (a, b) = (b, a)$   
using assms  
by simp
```

```
lemma  
  fixes a b::name2  
  shows ( $a \leftrightarrow b$ )  $\cdot (a, b) = (b, a)$ 
```

by *simp*

39 An example for multiple-sort atoms

```
datatype ty =  
  TVar string  
| Fun ty ty (- → -)
```

primrec

sort-of-ty::ty ⇒ *atom-sort*

where

```
sort-of-ty (TVar s) = Sort "TVar" [Sort s []]  
| sort-of-ty (Fun ty1 ty2) = Sort "Fun" [sort-of-ty ty1, sort-of-ty ty2]
```

lemma *sort-of-ty-eq-iff*:

shows *sort-of-ty* x = *sort-of-ty* y ⟷ x = y

apply(*induct* x *arbitrary*: y)

apply(*case-tac* [!] y)

apply(*simp-all*)

done

declare *sort-of-ty.simps* [*simp del*]

```
typedef var = {a. sort-of a ∈ range sort-of-ty}  
  by (rule-tac x=Atom (sort-of-ty x) y in exI, simp)
```

instantiation var :: *at-base*

begin

definition

$p \cdot a = \text{Abs-var } (p \cdot \text{Rep-var } a)$

definition

$\text{atom } a = \text{Rep-var } a$

instance

apply (*rule at-base-class*)

apply (*rule type-definition-var*)

apply (*rule atom-var-def*)

apply (*rule permute-var-def*)

done

end

Constructor for variables.

definition

$\text{Var} :: \text{nat} \Rightarrow \text{ty} \Rightarrow \text{var}$

where

$\text{Var } x \ t = \text{Abs-var } (\text{Atom } (\text{sort-of-ty } t) \ x)$

lemma *Var-eq-iff* [*simp*]:
shows $\text{Var } x \ s = \text{Var } y \ t \longleftrightarrow x = y \wedge s = t$
unfolding *Var-def*
by (*auto simp add: Abs-var-inject sort-of-ty-eq-iff*)

lemma *sort-of-atom-var* [*simp*]:
 $\text{sort-of } (\text{atom } (\text{Var } n \ ty)) = \text{sort-of-ty } ty$
unfolding *atom-var-def Var-def*
by (*simp add: Abs-var-inverse*)

lemma
assumes $\alpha \neq \beta$
shows $(\text{Var } x \ \alpha \leftrightarrow \text{Var } y \ \alpha) \cdot (\text{Var } x \ \alpha, \text{Var } x \ \beta) = (\text{Var } y \ \alpha, \text{Var } x \ \beta)$
using *assms* **by** *simp*

Projecting out the type component of a variable.

definition
 $ty\text{-of} :: \text{var} \Rightarrow \text{ty}$
where
 $ty\text{-of } x = \text{inv sort-of-ty } (\text{sort-of } (\text{atom } x))$

Functions *Var/ty-of* satisfy many of the same properties as *Atom/sort-of*.

lemma *ty-of-Var* [*simp*]:
shows $ty\text{-of } (\text{Var } x \ t) = t$
unfolding *ty-of-def*
unfolding *sort-of-atom-var*
apply (*rule inv-f-f*)
apply (*simp add: inj-on-def sort-of-ty-eq-iff*)
done

lemma *ty-of-permute* [*simp*]:
shows $ty\text{-of } (p \cdot x) = ty\text{-of } x$
unfolding *ty-of-def*
unfolding *atom-eqvt [symmetric]*
by (*simp only: sort-of-permute*)

40 Tests with subtyping and automatic coercions

declare [*coercion-enabled*]

atom-decl *var1*
atom-decl *var2*

declare [*coercion atom::var1* \Rightarrow *atom*]

declare [*coercion atom::var2* \Rightarrow *atom*]

lemma

```

fixes a::var1 and b::var2
shows  $a \# t \wedge b \# t$ 
oops

```

```

lemma
fixes as::var1 set
shows  $atom \ 'as \#* t$ 

```

```

oops

```

```

end

```

```

theory Eqvt
imports Nominal2-Base
begin

```

```

declare  $[[trace\text{-}eqvt = false]]$ 

```

```

lemma
fixes B::'a::pt
shows  $p \cdot (B = C)$ 
apply (perm-simp)
oops

```

```

lemma
fixes B::bool
shows  $p \cdot (B = C)$ 
apply (perm-simp)
oops

```

```

lemma
fixes B::bool
shows  $p \cdot (A \longrightarrow B = C)$ 
apply (perm-simp)
oops

```

```

lemma
shows  $p \cdot (\lambda(x::'a::pt). A \longrightarrow (B::'a \Rightarrow bool) x = C) = foo$ 
apply (perm-simp)
oops

```

```

lemma
shows  $p \cdot (\lambda(B::bool). A \longrightarrow (B = C)) = foo$ 
apply (perm-simp)

```

oops

lemma

shows $p \cdot (\lambda x y. \exists z. x = z \wedge x = y \longrightarrow z \neq x) = foo$
apply (*perm-simp*)

oops

lemma

shows $p \cdot (\lambda f x. f (g (f x))) = foo$
apply (*perm-simp*)

oops

lemma

fixes $p q::perm$
and $x::'a::pt$
shows $p \cdot (q \cdot x) = foo$
apply(*perm-simp*)

oops

lemma

fixes $p q r::perm$
and $x::'a::pt$
shows $p \cdot (q \cdot r \cdot x) = foo$
apply(*perm-simp*)

oops

lemma

fixes $p r::perm$
shows $p \cdot (\lambda q::perm. q \cdot (r \cdot x)) = foo$
apply (*perm-simp*)

oops

lemma

fixes $C D::bool$
shows $B (p \cdot (C = D))$
apply(*perm-simp*)

oops

declare [[*trace- $eqvt = false$*]]

there is no raw *eqvt*-rule for *The*

lemma $p \cdot (THE x. P x) = foo$
apply(*perm-strict-simp exclude: The*)
apply(*perm-simp exclude: The*)

oops

lemma

fixes $P :: (('b \Rightarrow bool) \Rightarrow ('b::pt)) \Rightarrow ('a::pt)$
shows $p \cdot (P The) = foo$

```

apply(perm-simp exclude: The)
oops

lemma
  fixes  $P :: ('a::pt) \Rightarrow ('b::pt) \Rightarrow bool$ 
  shows  $p \cdot (\lambda(a, b). P a b) = (\lambda(a, b). (p \cdot P) a b)$ 
apply(perm-simp)
oops

thm eqvts
thm eqvts-raw

ML  $\langle Nominal-ThmDecls.is-eqvt @\{context\} @\{term\ supp\} \rangle$ 

end

```