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Recursive Definitions

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Summary. The text contains some schemes which allow elimination of definitions by recursion.

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The articles [6], [5], [8], [7], [1], [9], [3], [2], and [4] provide the notation and terminology for this paper.

We use the following convention: n, k denote natural numbers, x, y, z, y_1, y_2 denote sets, and p denotes a finite sequence.

Let D be a set, let p be a partial function from D to $\mathbb{N}$, and let n be an element of D. Then $p(n)$ is a natural number.

In this article we present several logical schemes. The scheme *RecEx* deals with a set $\mathcal{A}$ and a ternary predicate $\mathcal{P}$, and states that:

> There exists a function f such that $\mathrm{dom}\, f = \mathbb{N}$ and $f(0) = \mathcal{A}$ and for every element n of $\mathbb{N}$ holds $\mathcal{P}[n, f(n), f(n+1)]$

provided the parameters meet the following requirements:

- For every natural number n and for every set x there exists a set y such that $\mathcal{P}[n,x,y]$, and
- For every natural number n and for all sets x, y_1, y_2 such that $\mathcal{P}[n,x,y_1]$ and $\mathcal{P}[n,x,y_2]$ holds $y_1 = y_2$.

The scheme *RecExD* deals with a non empty set $\mathcal{A}$, an element $\mathcal{B}$ of $\mathcal{A}$, and a ternary predicate $\mathcal{P}$, and states that:

> There exists a function f from $\mathbb{N}$ into $\mathcal{A}$ such that $f(0) = \mathcal{B}$ and for every element n of $\mathbb{N}$ holds $\mathcal{P}[n, f(n), f(n+1)]$

provided the parameters have the following property:

- For every natural number n and for every element x of $\mathcal{A}$ there exists an element y of $\mathcal{A}$ such that $\mathcal{P}[n,x,y]$.

The scheme *LambdaRecEx* deals with a set $\mathcal{A}$ and a binary functor $\mathcal{F}$ yielding a set, and states that:

> There exists a function f such that $\mathrm{dom}\, f = \mathbb{N}$ and $f(0) = \mathcal{A}$ and for every element n of $\mathbb{N}$ holds $f(n+1) = \mathcal{F}(n, f(n))$

for all values of the parameters.

The scheme *LambdaRecExD* deals with a non empty set $\mathcal{A}$, an element $\mathcal{B}$ of $\mathcal{A}$, and a binary functor $\mathcal{F}$ yielding an element of $\mathcal{A}$, and states that:

> There exists a function f from $\mathbb{N}$ into $\mathcal{A}$ such that $f(0) = \mathcal{B}$ and for every element n of $\mathbb{N}$ holds $f(n+1) = \mathcal{F}(n, f(n))$

for all values of the parameters.

The scheme *FinRecEx* deals with a set $\mathcal{A}$, a natural number $\mathcal{B}$, and a ternary predicate $\mathcal{P}$, and states that:

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There exists a finite sequence p such that $\operatorname{len} p = \mathcal{B}$ but $p(1) = \mathcal{A}$ or $\mathcal{B} = 0$ but for every n such that $1 \leq n$ and $n < \mathcal{B}$ holds $\mathcal{P}[n, p(n), p(n+1)]$

provided the parameters meet the following conditions:

- For every natural number n such that $1 \leq n$ and $n < \mathcal{B}$ and for every set x there exists a set y such that $\mathcal{P}[n,x,y]$, and
- For every natural number n such that $1 \leq n$ and $n < \mathcal{B}$ and for all sets x, y_1, y_2 such that $\mathcal{P}[n,x,y_1]$ and $\mathcal{P}[n,x,y_2]$ holds $y_1 = y_2$.

The scheme *FinRecExD* deals with a non empty set $\mathcal{A}$, an element $\mathcal{B}$ of $\mathcal{A}$, a natural number $\mathcal{C}$, and a ternary predicate $\mathcal{P}$, and states that:

There exists a finite sequence p of elements of $\mathcal{A}$ such that $\operatorname{len} p = \mathcal{C}$ but $p(1) = \mathcal{B}$ or $\mathcal{C} = 0$ but for every n such that $1 \leq n$ and $n < \mathcal{C}$ holds $\mathcal{P}[n, p(n), p(n+1)]$

provided the parameters have the following property:

- Let n be a natural number. Suppose $1 \leq n$ and $n < \mathcal{C}$. Let x be an element of $\mathcal{A}$. Then there exists an element y of $\mathcal{A}$ such that $\mathcal{P}[n,x,y]$.

The scheme *SeqBinOpEx* deals with a finite sequence $\mathcal{A}$ and a ternary predicate $\mathcal{P}$, and states that:

There exists x and there exists a finite sequence p such that $x = p(\operatorname{len} p)$ and $\operatorname{len} p = \operatorname{len} \mathcal{A}$ and $p(1) = \mathcal{A}(1)$ and for every k such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ holds $\mathcal{P}[\mathcal{A}(k+1), p(k), p(k+1)]$

provided the following conditions are met:

- For all k, x such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ there exists y such that $\mathcal{P}[\mathcal{A}(k+1),x,y]$, and
- For all k, x, y_1, y_2, z such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ and $z = \mathcal{A}(k+1)$ and $\mathcal{P}[z,x,y_1]$ and $\mathcal{P}[z,x,y_2]$ holds $y_1 = y_2$.

The scheme *LambdaSeqBinOpEx* deals with a finite sequence $\mathcal{A}$ and a binary functor $\mathcal{F}$ yielding a set, and states that:

There exists x and there exists a finite sequence p such that $x = p(\operatorname{len} p)$ and $\operatorname{len} p = \operatorname{len} \mathcal{A}$ and $p(1) = \mathcal{A}(1)$ and for every k such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ holds $p(k+1) = \mathcal{F}(\mathcal{A}(k+1), p(k))$

for all values of the parameters.

The scheme *RecUn* deals with a set $\mathcal{A}$, functions $\mathcal{B}$, $\mathcal{C}$, and a ternary predicate $\mathcal{P}$, and states that:

$\mathcal{B} = \mathcal{C}$

provided the parameters satisfy the following conditions:

- $\operatorname{dom} \mathcal{B} = \mathbb{N}$ and $\mathcal{B}(0) = \mathcal{A}$ and for every n holds $\mathcal{P}[n, \mathcal{B}(n), \mathcal{B}(n+1)]$,
- $\operatorname{dom} \mathcal{C} = \mathbb{N}$ and $\mathcal{C}(0) = \mathcal{A}$ and for every n holds $\mathcal{P}[n, \mathcal{C}(n), \mathcal{C}(n+1)]$, and
- For every n and for all sets x, y_1, y_2 such that $\mathcal{P}[n,x,y_1]$ and $\mathcal{P}[n,x,y_2]$ holds $y_1 = y_2$.

The scheme *RecUnD* deals with a non empty set $\mathcal{A}$, an element $\mathcal{B}$ of $\mathcal{A}$, functions $\mathcal{C}$, $\mathcal{D}$ from $\mathbb{N}$ into $\mathcal{A}$, and a ternary predicate $\mathcal{P}$, and states that:

$\mathcal{C} = \mathcal{D}$

provided the parameters meet the following requirements:

- $\mathcal{C}(0) = \mathcal{B}$ and for every n holds $\mathcal{P}[n, \mathcal{C}(n), \mathcal{C}(n+1)]$,
- $\mathcal{D}(0) = \mathcal{B}$ and for every n holds $\mathcal{P}[n, \mathcal{D}(n), \mathcal{D}(n+1)]$, and
- For every natural number n and for all elements x, y_1, y_2 of $\mathcal{A}$ such that $\mathcal{P}[n,x,y_1]$ and $\mathcal{P}[n,x,y_2]$ holds $y_1 = y_2$.

The scheme *LambdaRecUn* deals with a set $\mathcal{A}$, a binary functor $\mathcal{F}$ yielding a set, and functions $\mathcal{B}$, $\mathcal{C}$, and states that:

$\mathcal{B} = \mathcal{C}$

provided the parameters meet the following conditions:

- $\operatorname{dom} \mathcal{B} = \mathbb{N}$ and $\mathcal{B}(0) = \mathcal{A}$ and for every n holds $\mathcal{B}(n+1) = \mathcal{F}(n, \mathcal{B}(n))$, and
- $\operatorname{dom} \mathcal{C} = \mathbb{N}$ and $\mathcal{C}(0) = \mathcal{A}$ and for every n holds $\mathcal{C}(n+1) = \mathcal{F}(n, \mathcal{C}(n))$.

The scheme *LambdaRecUnD* deals with a non empty set $\mathcal{A}$, an element $\mathcal{B}$ of $\mathcal{A}$, a binary functor $\mathcal{F}$ yielding an element of $\mathcal{A}$, and functions $\mathcal{C}$, $\mathcal{D}$ from $\mathbb{N}$ into $\mathcal{A}$, and states that:

$\mathcal{C} = \mathcal{D}$

provided the following conditions are satisfied:

- $\mathcal{C}(0) = \mathcal{B}$ and for every n holds $\mathcal{C}(n+1) = \mathcal{F}(n, \mathcal{C}(n))$, and

- $\mathcal{D}(0) = \mathcal{B}$ and for every n holds $\mathcal{D}(n+1) = \mathcal{F}(n, \mathcal{D}(n))$.

The scheme *LambdaRecUnR* deals with a real number $\mathcal{A}$, a binary functor $\mathcal{F}$ yielding a set, and functions $\mathcal{B}$, $\mathcal{C}$ from $\mathbb{N}$ into $\mathbb{R}$, and states that:

$\mathcal{B} = \mathcal{C}$

provided the parameters meet the following conditions:

- $\mathcal{B}(0) = \mathcal{A}$ and for every n holds $\mathcal{B}(n+1) = \mathcal{F}(n, \mathcal{B}(n))$, and
- $\mathcal{C}(0) = \mathcal{A}$ and for every n holds $\mathcal{C}(n+1) = \mathcal{F}(n, \mathcal{C}(n))$.

The scheme *FinRecUn* deals with a set $\mathcal{A}$, a natural number $\mathcal{B}$, finite sequences $\mathcal{C}$, $\mathcal{D}$, and a ternary predicate $\mathcal{P}$, and states that:

$\mathcal{C} = \mathcal{D}$

provided the parameters meet the following requirements:

- For every n such that $1 \leq n$ and $n < \mathcal{B}$ and for all sets x, y_1, y_2 such that $\mathcal{P}[n, x, y_1]$ and $\mathcal{P}[n, x, y_2]$ holds $y_1 = y_2$,
- $\operatorname{len} \mathcal{C} = \mathcal{B}$ but $\mathcal{C}(1) = \mathcal{A}$ or $\mathcal{B} = 0$ but for every n such that $1 \leq n$ and $n < \mathcal{B}$ holds $\mathcal{P}[n, \mathcal{C}(n), \mathcal{C}(n+1)]$, and
- $\operatorname{len} \mathcal{D} = \mathcal{B}$ but $\mathcal{D}(1) = \mathcal{A}$ or $\mathcal{B} = 0$ but for every n such that $1 \leq n$ and $n < \mathcal{B}$ holds $\mathcal{P}[n, \mathcal{D}(n), \mathcal{D}(n+1)]$.

The scheme *FinRecUnD* deals with a non empty set $\mathcal{A}$, an element $\mathcal{B}$ of $\mathcal{A}$, a natural number $\mathcal{C}$, finite sequences $\mathcal{D}$, $\mathcal{E}$ of elements of $\mathcal{A}$, and a ternary predicate $\mathcal{P}$, and states that:

$\mathcal{D} = \mathcal{E}$

provided the parameters meet the following requirements:

- For every n such that $1 \leq n$ and $n < \mathcal{C}$ and for all elements x, y_1, y_2 of $\mathcal{A}$ such that $\mathcal{P}[n, x, y_1]$ and $\mathcal{P}[n, x, y_2]$ holds $y_1 = y_2$,
- $\operatorname{len} \mathcal{D} = \mathcal{C}$ but $\mathcal{D}(1) = \mathcal{B}$ or $\mathcal{C} = 0$ but for every n such that $1 \leq n$ and $n < \mathcal{C}$ holds $\mathcal{P}[n, \mathcal{D}(n), \mathcal{D}(n+1)]$, and
- $\operatorname{len} \mathcal{E} = \mathcal{C}$ but $\mathcal{E}(1) = \mathcal{B}$ or $\mathcal{C} = 0$ but for every n such that $1 \leq n$ and $n < \mathcal{C}$ holds $\mathcal{P}[n, \mathcal{E}(n), \mathcal{E}(n+1)]$.

The scheme *SeqBinOpUn* deals with a finite sequence $\mathcal{A}$, sets $\mathcal{B}$, $\mathcal{C}$, and a ternary predicate $\mathcal{P}$, and states that:

$\mathcal{B} = \mathcal{C}$

provided the following conditions are satisfied:

- For all k, x, y_1, y_2, z such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ and $z = \mathcal{A}(k+1)$ and $\mathcal{P}[z, x, y_1]$ and $\mathcal{P}[z, x, y_2]$ holds $y_1 = y_2$,
- There exists a finite sequence p such that $\mathcal{B} = p(\operatorname{len} p)$ and $\operatorname{len} p = \operatorname{len} \mathcal{A}$ and $p(1) = \mathcal{A}(1)$ and for every k such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ holds $\mathcal{P}[\mathcal{A}(k+1), p(k), p(k+1)]$, and
- There exists a finite sequence p such that $\mathcal{C} = p(\operatorname{len} p)$ and $\operatorname{len} p = \operatorname{len} \mathcal{A}$ and $p(1) = \mathcal{A}(1)$ and for every k such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ holds $\mathcal{P}[\mathcal{A}(k+1), p(k), p(k+1)]$.

The scheme *LambdaSeqBinOpUn* deals with a finite sequence $\mathcal{A}$, a binary functor $\mathcal{F}$ yielding a set, and sets $\mathcal{B}$, $\mathcal{C}$, and states that:

$\mathcal{B} = \mathcal{C}$

provided the parameters meet the following conditions:

- There exists a finite sequence p such that $\mathcal{B} = p(\operatorname{len} p)$ and $\operatorname{len} p = \operatorname{len} \mathcal{A}$ and $p(1) = \mathcal{A}(1)$ and for every k such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ holds $p(k+1) = \mathcal{F}(\mathcal{A}(k+1), p(k))$, and
- There exists a finite sequence p such that $\mathcal{C} = p(\operatorname{len} p)$ and $\operatorname{len} p = \operatorname{len} \mathcal{A}$ and $p(1) = \mathcal{A}(1)$ and for every k such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ holds $p(k+1) = \mathcal{F}(\mathcal{A}(k+1), p(k))$.

The scheme *DefRec* deals with a set $\mathcal{A}$, a natural number $\mathcal{B}$, and a ternary predicate $\mathcal{P}$, and states that:

(i) There exists a set y and there exists a function f such that $y = f(\mathcal{B})$ and $\operatorname{dom} f = \mathbb{N}$ and $f(0) = \mathcal{A}$ and for every n holds $\mathcal{P}[n, f(n), f(n+1)]$, and

(ii) for all sets y_1, y_2 such that there exists a function f such that $y_1 = f(\mathcal{B})$ and $\operatorname{dom} f = \mathbb{N}$ and $f(0) = \mathcal{A}$ and for every n holds $\mathcal{P}[n, f(n), f(n+1)]$ and there exists a function f such that $y_2 = f(\mathcal{B})$ and $\operatorname{dom} f = \mathbb{N}$ and $f(0) = \mathcal{A}$ and for every n holds $\mathcal{P}[n, f(n), f(n+1)]$ holds $y_1 = y_2$

provided the following conditions are satisfied:

- For all n, x there exists y such that $\mathcal{P}[n,x,y]$, and
- For all n, x, y_1, y_2 such that $\mathcal{P}[n,x,y_1]$ and $\mathcal{P}[n,x,y_2]$ holds $y_1 = y_2$.

The scheme *LambdaDefRec* deals with a set $\mathcal{A}$, a natural number $\mathcal{B}$, and a binary functor $\mathcal{F}$ yielding a set, and states that:

(i) There exists a set y and there exists a function f such that $y = f(\mathcal{B})$ and $\operatorname{dom} f = \mathbb{N}$ and $f(0) = \mathcal{A}$ and for every n holds $f(n+1) = \mathcal{F}(n, f(n))$, and

(ii) for all sets y_1, y_2 such that there exists a function f such that $y_1 = f(\mathcal{B})$ and $\operatorname{dom} f = \mathbb{N}$ and $f(0) = \mathcal{A}$ and for every n holds $f(n+1) = \mathcal{F}(n, f(n))$ and there exists a function f such that $y_2 = f(\mathcal{B})$ and $\operatorname{dom} f = \mathbb{N}$ and $f(0) = \mathcal{A}$ and for every n holds $f(n+1) = \mathcal{F}(n, f(n))$ holds $y_1 = y_2$

for all values of the parameters.

The scheme *DefRecD* deals with a non empty set $\mathcal{A}$, an element $\mathcal{B}$ of $\mathcal{A}$, a natural number $\mathcal{C}$, and a ternary predicate $\mathcal{P}$, and states that:

(i) There exists an element y of $\mathcal{A}$ and there exists a function f from $\mathbb{N}$ into $\mathcal{A}$ such that $y = f(\mathcal{C})$ and $f(0) = \mathcal{B}$ and for every n holds $\mathcal{P}[n, f(n), f(n+1)]$, and

(ii) for all elements y_1, y_2 of $\mathcal{A}$ such that there exists a function f from $\mathbb{N}$ into $\mathcal{A}$ such that $y_1 = f(\mathcal{C})$ and $f(0) = \mathcal{B}$ and for every n holds $\mathcal{P}[n, f(n), f(n+1)]$ and there exists a function f from $\mathbb{N}$ into $\mathcal{A}$ such that $y_2 = f(\mathcal{C})$ and $f(0) = \mathcal{B}$ and for every n holds $\mathcal{P}[n, f(n), f(n+1)]$ holds $y_1 = y_2$

provided the following conditions are met:

- For every natural number n and for every element x of $\mathcal{A}$ there exists an element y of $\mathcal{A}$ such that $\mathcal{P}[n,x,y]$, and
- For every natural number n and for all elements x, y_1, y_2 of $\mathcal{A}$ such that $\mathcal{P}[n,x,y_1]$ and $\mathcal{P}[n,x,y_2]$ holds $y_1 = y_2$.

The scheme *LambdaDefRecD* deals with a non empty set $\mathcal{A}$, an element $\mathcal{B}$ of $\mathcal{A}$, a natural number $\mathcal{C}$, and a binary functor $\mathcal{F}$ yielding an element of $\mathcal{A}$, and states that:

(i) There exists an element y of $\mathcal{A}$ and there exists a function f from $\mathbb{N}$ into $\mathcal{A}$ such that $y = f(\mathcal{C})$ and $f(0) = \mathcal{B}$ and for every natural number n holds $f(n+1) = \mathcal{F}(n, f(n))$, and

(ii) for all elements y_1, y_2 of $\mathcal{A}$ such that there exists a function f from $\mathbb{N}$ into $\mathcal{A}$ such that $y_1 = f(\mathcal{C})$ and $f(0) = \mathcal{B}$ and for every natural number n holds $f(n+1) = \mathcal{F}(n, f(n))$ and there exists a function f from $\mathbb{N}$ into $\mathcal{A}$ such that $y_2 = f(\mathcal{C})$ and $f(0) = \mathcal{B}$ and for every natural number n holds $f(n+1) = \mathcal{F}(n, f(n))$ holds $y_1 = y_2$

for all values of the parameters.

The scheme *SeqBinOpDef* deals with a finite sequence $\mathcal{A}$ and a ternary predicate $\mathcal{P}$, and states that:

(i) There exists x and there exists a finite sequence p such that $x = p(\operatorname{len} p)$ and $\operatorname{len} p = \operatorname{len} \mathcal{A}$ and $p(1) = \mathcal{A}(1)$ and for every k such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ holds $\mathcal{P}[\mathcal{A}(k+1), p(k), p(k+1)]$, and

(ii) for all x, y such that there exists a finite sequence p such that $x = p(\operatorname{len} p)$ and $\operatorname{len} p = \operatorname{len} \mathcal{A}$ and $p(1) = \mathcal{A}(1)$ and for every k such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ holds $\mathcal{P}[\mathcal{A}(k+1), p(k), p(k+1)]$ and there exists a finite sequence p such that $y = p(\operatorname{len} p)$ and $\operatorname{len} p = \operatorname{len} \mathcal{A}$ and $p(1) = \mathcal{A}(1)$ and for every k such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ holds $\mathcal{P}[\mathcal{A}(k+1), p(k), p(k+1)]$ holds $x = y$

provided the following conditions are satisfied:

- For all k, y such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ there exists z such that $\mathcal{P}[\mathcal{A}(k+1), y, z]$, and
- For all k, x, y_1, y_2, z such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ and $z = \mathcal{A}(k+1)$ and $\mathcal{P}[z,x,y_1]$ and $\mathcal{P}[z,x,y_2]$ holds $y_1 = y_2$.

The scheme *LambdaSeqBinOpDef* deals with a finite sequence $\mathcal{A}$ and a binary functor $\mathcal{F}$ yielding a set, and states that:

(i) There exists x and there exists a finite sequence p such that $x = p(\operatorname{len} p)$ and $\operatorname{len} p = \operatorname{len} \mathcal{A}$ and $p(1) = \mathcal{A}(1)$ and for every k such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ holds $p(k+1) = \mathcal{F}(\mathcal{A}(k+1), p(k))$, and

(ii) for all x, y such that there exists a finite sequence p such that $x = p(\operatorname{len} p)$ and $\operatorname{len} p = \operatorname{len} \mathcal{A}$ and $p(1) = \mathcal{A}(1)$ and for every k such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$

holds $p(k+1) = \mathcal{F}(\mathcal{A}(k+1), p(k))$ and there exists a finite sequence p such that $y = p(\operatorname{len} p)$ and $\operatorname{len} p = \operatorname{len} \mathcal{A}$ and $p(1) = \mathcal{A}(1)$ and for every k such that $1 \leq k$ and $k < \operatorname{len} \mathcal{A}$ holds $p(k+1) = \mathcal{F}(\mathcal{A}(k+1), p(k))$ holds $x = y$

for all values of the parameters.

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