# Appendix A
# A Proofs of Lemmas 1, 2 and Theorem 4.5 from Chapter 4

*All's well that ends well*

## A.1 Proof of Lemma 1

For the sake of convenience, let's repeatedly adduce the basic definition used in Lemma 1 and the formulation of this lemma.

**Definition.** Let $B$ be an arbitrary conceptual basis, $n \geq 1$, for $i = 1, \ldots, n$, $c_i \in D(B)$, $s = c_1 \ldots c_n$, $1 \leq k \leq n$. Then let the expressions $lt_1(s, k)$ and $lt_2(s, k)$ denote the number of the occurrences of the symbol $'('$ and the symbol $'\langle'$ respectively in the substring $c_1 \ldots, c_k$ of the string $s = c_1 \ldots c_n$.

Let the expressions $rt_1(s, k)$ and $rt_2(s, k)$ designate the number of the occurrences of the symbol $')'$ and the symbol $'\langle'$ into the substring $c_1 \ldots c_k$ of the string $s$. If the substring $c_1 \ldots c_k$ doesn't include the symbol $'('$ or the symbol $'\langle'$, then let respectively

$$lt_1(s, k) = 0,\ lt_2(s, k) = 0\,,$$

$$rt_1(s, k) = 0,\ rt_2(s, k) = 0\,.$$

**Lemma 1.** Let $B$ be an arbitrary conceptual basis, $y \in Ls(B)$, $n \geq 1$, for $i = 1, \ldots, n$, $c_i \in D(B)$, $y = c_1 \ldots c_n$. Then

(a) if $n > 1$, then for every $k = 1, \ldots, n-1$ and every $m = 1, 2$

$$lt_m(y, k) \geq rt_m(y, k);$$

$$(b)\ \ lt_m(y, n) = rt_m(y, n).$$

**Proof**. Let's agree that for arbitrary sequence $s \in Ds^+(B)$, the length of $S$ ( the number of elements from $Ds(B)$ ) will be denoted as $l(s)$ or $Length(s)$.

Let $B$ be an arbitrary conceptual basis, $y \in Ls(B)$, $n \geq 1$, for $I = 1, \ldots, n$, $c_i \in D(B)$, $y = {}_1 \ldots {}_n$. If $n = 1$, then it immediately follows from the rules $P[0], P[1], \ldots, P[10]$ that $y \in X(B) \cup V(B)$.

According to the definition of conceptual basis, the symbols from the sets $X(B)$ and $V(B)$ are distinct from the symbols $'('$, $')'$, $'\langle'$, $'\rangle'$. That is why

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$$lt_1(y,n) = rt_1(y,n) = 0,$$

$$lt_2(y,n) = rt_2(y,n) = 0.$$

If $n > 1$, then $y$ has been constructed with the help of some rules from the list $P[1], \dots, P[10]$ (in addition to the rule $P[0]$). Let's prove the lemma by induction, using the number $q$ of the applications of the rules $P[1], \dots, : P[10]$ for building $y$ as the parameter of induction.

**Part 1.** Let's assume that $q = 1$.

**Case 1.1.** Let a string $y$ be obtained by applying just one time the rule $P[2]$ or $P[4]$. Then

$$y = f(u_1, \dots, u_m) \text{ or } y = r(u_1, \dots, u_m),$$

where $m \geq 1,\ f \in F(B),\ r \in R(B)$,

$$u_1, \dots, u_m \in X(B) \cup V(B).$$

Obviously, in this situation

$$lt_1(y,\,1) = rt_1(y,\,1) = 0,\ lt_1(y,\,n) = rt_1(y,\,n) = 1,$$

for $1 < k < n$, $lt_2(y,\,k) = 1$, $rt_2(y,\,k) = 0$,

for $k = 1, \dots, n$ $lt_2(y,\,k) = rt_2(y,\,k) = 0$.

**Case 1.2.** If $y$ is obtained by applying the rule $P[3]$, then there are such elements $u_1, u_2 \in X(B) \cup V(B)$, that $y = (u_1 \equiv u_2)$. Then for $k = 1, \dots, n-1$,

$$lt_1(y,\,k) = 1,\ rt_1(y,\,k) = 0,$$

$$lt_1(y,\,n) = rt_1(y,\,n) = 1,$$

for $k = 1, \dots, n$,

$$lt_2(y,\,k) = rt_2(y,\,k) = 0.$$

**Case 1.3.** Let's suppose that the string $y$ is constructed as a result of applying just just one time the rule $P[7]$, and with this aim the binary logical connective $bin \in \{\wedge, \vee\}$ and the elements $d_1, \dots, d_m \in X(B) \cup V(B)$, where $m > 1$, were used. Then

$$y = (d_1\, bin\, d_2\, bin \dots bin\, d_m).$$

Therefore, for $k = 1, \dots, n-1$,

$$lt_1(y,\,k) = 1,\ rt_1(y,\,k) = 0,$$

$$lt_1(y,\,n) = 1,\ rt_1(y,\,n) = 1,$$

for $k = 1, \dots, n,\ \ lt_2(y,\,k) = rt_2(y,\,k) = 0$.

**Case 1.4.** If $y$ is obtained by applying just one time the rule $P[1]$ or $P[6]$, then $y$ doesn't contain the symbols $'(', ')', '\langle', '\rangle'$. Then

$$lt_1(y,\,k) = rt_1(y,\,k) = lt_2(y,\,k) = rt_2(y,\,k) = 0$$

for $k = 1, \dots, n$.

**Case 1.5.** The analysis of the rule $P[9$ shows that the string $y$ couldn't be constructed from the elements of the sets $X(B)$ and $V(B)$ by means of applying just one time the rule $P[9]$ (and, possibly, the rule $P[0]$).

Supposing that it is not true we have $y = Qv(concept)\,descr$, where $Q \in \{\forall,\ exists\}$, $v \in V(B)$, $concept \in X(B)$, $descr\,\&\,P \in Ts(B)$, where $P$ is the sort "a meaning of proposition." But the string $des$ is to include the variable $v$, where $tp(v) = [entity]$. That is why $descr = v$. This relationship contradicts the relationship $descr\,\&\,P \in Ts(B)$.

**Case 1.6.** If the string $y$ was obtained by applying one time the rule $P[10]$, $y$ doesn't include the symbols $'(', ')'$, and the first symbol of $y$ is $'\langle'$. Then for $k = 1, \dots, n$,

$$lt_1(y, k) = 1,\ rt_1(y, k) = 0,$$

for $k = 1, \dots, n-1$, $lt_2(y, k) = 1$, $rt_2(y, k) = 0$,

$$lt_2(y, n) = rt_2(y, n) = 1.$$

**Part 2.** Let such $q \geq 1$ exist that the statements (a), (b) of Lemma 1 are valid for every string $y$ constructed out of the elements from the sets $X(B)$ and $V(B)$ by applying not more than $q$ times the rules $P[1], \dots, P[10]$ (and, possibly, by applying arbitrarily many times the rule $P[0]$).

Let's prove that in this case the statements (a), (b) are true for every string $y$ obtained by applying $q+1$ times the rules from the list $P[1], \dots, P[10]$. Consider possible cases.

**Case 2.1.** $y = f(a_1, \dots, a_m)$ or $y = r(a_1, \dots, a_m)$, where $m > 1$. For $a_1, \dots, a_m$ the conditions (a), (b) are satisfied. That is why, obviously,

$$lt_1(y, 1) = rt_1(y, 1) = 0,$$

$$lt_1(y, 2) = 1,\ rt_1(y, 2) = 0;$$

for $i = 3, \dots, n-1$,

$$lt_1(y, i) > rt_1(y, i),\ lt_1(y, n) = rt_1(y, n).$$

**Case 2.2.** If $y$ is the string $(a_1 \equiv a_2)$, then it follows from the inductive assumption that

$$lt_1(y, 1) = 1,\ rt_1(y, 1) = 0,$$

for $i = 2, \dots, n-1$, $lt_1(y, n) = rt_1(y, n)$.

**Case 2.3.** Let such a binary logical connective $b \in \{\wedge, \vee\}$, such $m > 1$, and such strings $a_1, \dots, a_m$ exist that $y$ was obtained from $b$, $a_1, \dots, a_m$ by applying just one time the rule $P[7]$. Then

$$y = (a_1\, b\, a_2\, b \dots b\, a_m).$$

Let $Length(a_1) = n_1, \ldots, Length(a_m) = n_m$. Obviously, for $a_1, \ldots, a_m$ the statements (a), (b) of Lemma 1 are valid. Let's notice that the connective $b$ is located in $y$ in the positions

$$n_1 + 2,\, n_1 + n_2 + 3,\, n_1 + \ldots + n_m + (m+1);$$

then

$$lt_1(y, 1) = 1,\, rt_1(y, 1) = 0;$$

for $p = n_1 + 2,\, n_1 + n_2 + 3,\, n_1 + n_2 + \ldots + n_m + m + 1$,

$$rt_1(y, p) = lt_1(y, p) - 1;$$

for $i = 1, \ldots, m-1$ and for every such $p$ that

$$n_1 + \ldots + n_i + i + 1 < p < n_1 + \ldots + n_i + n_{i+1} + i + 2.$$

$$rt_1(y, p) \leq lt_1(y, p) - 1;$$
$$lt_1(y, n) = rt_1(y, n).$$

## A.2 Proof of Lemma 2

For the sake of convenience, let's repeatedly adduce the formulation of Lemma 2 from Sect. 3.8.

**Lemma 2.** Let $B$ be an arbitrary conceptual basis, $y \in Ls(B)$, $n > 1$, $y = c_1 \ldots c_n$, where for $i = 1, \ldots, n$, $c_i \in D(B)$, the string $y$ includes the comma or any of the symbols $\equiv$, $\wedge$, $vee$, and $k$ be such arbitrary natural number that $1 < k < n$. Then

(a) if $c_k$ is one of the symbols $\equiv$, $\wedge$, $\vee$, then

$$lt_1(y, k) > rt_1(y, k) \geq 0;$$

(b) if $c_k$ is the comma, then at least one of the following relationships takes place:

$$lt_1(y, k) > rt_1(y, k) \geq 0,$$

$$lt_2(y, k) > rt_2(y, k) \geq 0.$$

**Proof**. Let for $B$ and $y$ the assumptions of Lemma 2 are true, and

$$Symb = \{\equiv, \wedge, vee\}.$$

Since $y$ contains at least one of the elements of the set $Symb$, the string $y$ is constructed out of the elements of the set $X(B) \cup V(B)$ and several auxiliary symbols by applying $r$ times, where $r \geq 1$, some rules from the list $P[1], \ldots, P[10]$ (and, possibly, by applying several times the rule $P[0]$).

Let's prove the lemma by induction on $r$.

**Case 1.** If $r = 1$, then the truth of the goal statement for $y$ immediately follows from the analysis of all situations considered in Part 1of the proof of Lemma 1.

**Case 2 (inductive step).** Let such $r \geq 1$ exist that the statement of the lemma is true for arbitrary conceptual basis and for every such $y \in Ls(B)$ that n the process of constructing $y$, $m$ rules from the list $P[1], \ldots, P[10]$ were used, where $1 \leq m \leq r$. Let's prove that in this case the statement of the lemma is true and for every such $z \in Ls(B)$ that, while constructing $y$, $r+1$ rules from the list $P[1], \ldots, P[10]$ were used.

**Case 2.1a.** Let the rule $P[7]$ be used on the last step of constructing the string $z$. Then the string $z$ can be represented in the form

$$z = (y_1\, q\, y_2\, q\, \ldots\, q\, y_m),$$

where $m > 1$, $q \in \{\wedge, \vee\}$, for $i = 1, \ldots, m$, $y_i \in Ls(B)$. According to inductive assumption, for constructing every string from the strings $y_1, \ldots, y_m$, the rules $P[1], \ldots, P[10]$ were employed not more than $r$ times.

Let $2 < k < l(y_1) + 1$. Then, obviously, the symbol $c_k$ is an inner element of the string $y_1$. According to inductive assumption, if $lt_1(y_1, k-1) > 0$, then $lt_1(y_1, k-1) > rt_1(z, k-1)$; if $lt_2(y_1, k-1) > 0$, then $lt_2(y_1, k-1) > rt_2(y_1, k-1)$.

But $lt_1(z, k) = lt_1(y_1, k-1) + 1,\ rt_1(z, k) = rt_1(y_1, k-1)$, that is why $lt_1(z, k) > rt_1(z, k)$.

Besides, $lt_2(z, k) = lt_2(y_1, k-1),\ rt_2(z, k) = rt_2(y_1, k-1)$.

That is why, in accordance with inductive assumption, if $lt_2(z, k) > 0$, then $lt_2(z, k) > rt_2(z, k)$.

**Case 2.1b.** Let's assume, as above, that the rule $P[7]$ was employed at the last step of constructing the string $z$ and that the string $z$ can be represented in the form

$$(y_1\, q\, y_2\, q\, \ldots\, q\, y_m),$$

where $m > 1$, $q \in \{\wedge, \vee\}$, for $i = 1, \ldots, m$, $y_i \in Ls(B)$. Besides, let there be such $i$, $1 \leq i \leq m$, that

$$1 + l(y_1) + 1 + \ldots + l(y_i) + 2 < k < 1 + l(y_1) + 1 + \ldots + l(y_i) + 1 + l(y_{i+1}),$$

where $l(y_h) = Length(y_h)$, $h = 1, \ldots, i+1$. This means that the symbol $_k$ is an inner element of a certain substring $_{i+1} \in Ls(B)$.

Let the k th position of the considered string $z$ coincide with the -th position of the string $y_{i+1}$. Then

$$lt_1(z, k) = 1 + lt_1(y_1, l(y_1)) + \ldots + lt_1(y_i, l(y_i)) + lt_1(y_{i+1}, p),$$

$$rt_1(z, k) = rt_1(y_1, l(y_1)) + \ldots + rt_1(y_i, l(y_i,)) + rt_1(y_{i+1}, p).$$

In accordance with Lemma 1, for $j = 1, \ldots, i$,

$$lt_1(y_j, l(y_j)) = rt_1(y_j,$$

$$l(y_j)), lt_2(y_j, l(y_j)) = rt_2(y_j, l(y_j)),$$

$$lt_1(y_{+1}, p) \geq rt_1(y_{j+1}, p).$$

That is why $lt_1(z, k) > rt_1(z, k)$.

**Case 2.1c.** Let there exist such $m > 1$, $y_1, \ldots, y_m \in Ls(B)$, $q \in \{\wedge, \vee\}$ that

$$z = (y_1\, q\, y_2\, q \ldots q\, y_m),$$

and there is such $i$, $1 \leq i < m$ that

$$k = 1 + l(y_1) + 1 + \ldots + l(y_i) + 1 = l(y_1) + \ldots + l(y_i) + i + 1.$$

This means that $c_k$ is an occurrence of the logical connective $q$, separating $y_i$ and $y_i + 1$. It follows from Lemma 1 that for $s = 1, \ldots, i$,

$$lt_1(y_s, l(y_s)) = rt_1(y_s, l(y_s)).$$

That is why

$$lt_1(z, k) = 1 + lt_1(y_1, l(y_1)) + \ldots + lt_1(y_i, l(y_i)),$$

$$rt_1(z, k) = rt_1(y_1, l(y_1)) + \ldots + rt_1(y_i, l(y_i)).$$

Therefore, $lt_1(z, k) = rt_1(z, k) + 1$.

**Case 2.2.** During the last step of constructing the string $z$, the rule $P[3]$ has been used. In this situation, there are such $y_0, y_2 \in Ls(B)$ that $z$ can be represented in the form $(y_0 \equiv y_2)$. Obviously, this situation can be considered similar to the Case 2.1 for $m = 2$.

**Case 2.3.** On the last step of constructing the string $z$, one of the rules $P[2]$ or $P[4]$ was applied. Then there are such $y_1, \ldots, y_n \in Ls(B)$ that $z$ can be represented in the form $f(y_1, \ldots, y_n)$ or in the form $r(y_1, \ldots, y_n)$ respectively, where $f$ is an $n$-functional symbol, $r$ is an $n$-ary relational symbol. Obviously, this case is considered similar to the Case 2.1.

**Case 2.4.** During the final step of constructing the string $z$, one of the rules $P[8]$ or $[9]$ or $[10]$ has been used. These cases are to be considered similar to the Case 2.1 too.

## A.3 Proof of Theorem 4.5

Let there be an arbitrary conceptual basis, $z \in Ls(B) \setminus (X(B) \cup V(B))$. Then it directly follows from the structure of the rules $P[0]$, $P[1]$, $\ldots$, $P[10]$ and the definition of the set $Ls(B)$ the existence of such $k$, where $1 \leq k \leq 10$, $n \geq 1$, and $y_0, y_1, \ldots, y_n \in Ls(B)$ that

$$y_0 \,\&\, y_1 \,\&\, \ldots \,\&\, y_n \,\&\, z \in Ynr_{10}^k(B).$$

That is why the main attention is to be paid to proving the uniqueness of such $n+3$-tuple $(k, n, y_0, \ldots, y_n)$. Remember that, in accordance with the definition from Sect. 3.8, for arbitrary conceptual basis,

$$D(B) = X(B) \cup V(B) \cup \{',', '(', ')', ':', '*', '\langle', '\rangle'\},$$

$$Ds(B) = D(B) \cup \{'\&'\},$$

$D^+(B)$ and $Ds^+(B)$ are the sets of all non empty finite sequences of the elements from $D(B)$ and $Ds(B)$ respectively.

Suppose that $B$ is an arbitrary conceptual basis, $z$ is an arbitrary formula from $Ls(B) \setminus (X(B) \cup V(B))$, $1 \leq k \leq 10$, $n \geq 1$, and $y_0, y_1, \ldots, y_n$ are such formulas from $Ls(B)$ that

$$y_0 \,\&\, y_1 \,\&\, \ldots \,\&\, y_n \,\&\, z \in Ynr_{10}^k(B).$$

Let's prove that in this case the $n+3$-tuple $(k, n, y_0, \ldots, y_n)$ is the only such $n+3$-tuple that for this tuple the above relationship takes place. For achieving this goal, it is necessary to consider rather many possible cases.

The length of arbitrary string $s \in Ds^+(B)$ (the number of elements from $Ds(B)$) will denote, as before, $l(s)$. With respect to our agreement, the elements of arbitrary primary informational universe $X(B)$ and the variables from the set $V(B)$ are considered as symbols, i.e as non structured elements. That is why the length $l(d$ of arbitrary $d \in (X(B) \cup V(B)$ is equal to 1. The number 0 will be considered as the lenth of empty string $e$.

**Case 1.** The first symbol of the string $z$, denoted as $z[1]$, is the left parenthesis "(". Then, obviously, $k = 3$ or $k = 7$. If $k = 3$, then $n = 2$, and $z$ is the string of the form $(y_0 \equiv y_2)$, and $y_1$ is the symbol $\equiv$.

If $k = 7$, then $n \geq 2$, $y_0$ is the logical connective $\vee$ or $\wedge$, and $z$ is the string of the form

$$(y_1\, y_0\, y_2\, y_0 \ldots y_0\, y_n).$$

That is, $z$ is the string of the form $(y_1 \wedge y_2 \wedge \ldots \wedge y_n)$ in case $y_0 = \wedge$ and the string of the form $(y_1 \vee y_2 \vee \ldots \vee y_n)$ in case $y_0 = \vee$.

Suppose that $z$ is the string of the form $(y_0 \equiv y_2)$, $y_0, y_2 \in D^+(B)$ and prove that it is impossible to present $z$ in a different way. It will be a proof by contradiction.

**Case 1a.** Suppose that there are such $w_1, w_2 \in Ls(B)$ that $l(y_1) > l(w_1)$, and $z$ can be represented in the form $(w_1 \equiv w_2)$. Then the string $w_1 \equiv$ is the beginning of the string $y_0$. Let there be such $k$, $m$ that

$$1 \leq k < m,\ y_1 = c_1 \ldots c_m,$$

$$w_1 = c_1 \ldots c_k,$$

where $c_1 \ldots c_m \in D(B.)$ Then $c_{k+1} = ' \equiv '$, and, since no one string from $Ls(B)$ has no ending being the symbol $' \equiv '$, the inequality $k+1 < m$ is valid.

Since $y_0$ includes the symbol $' \equiv '$, then the string $y_1$ includes the left parenthesis $'('$ in a certain position $j < k+1$. That is why

$lt_1(y_1, k+1) > 0$. But it follows from the relationship $c_{k+1} = ' \equiv '$ (in accordance with Lemma 2) that

$$lt_1(y_0, k+1) > rt_1(y_0, k+1).$$

Obviously,

$$lt_1(y_0, k+1) = lt_1(w_1, k),$$

$$rt_1(y_0, k+1) = rt_1(w_1, k).$$

That is why $lt_1(w_1, k) > rt_1(w_1, k)$. However, with respect to Lemma 1, it follows from $w_1 \in Ls(B)$ and $k = l(w_1)$ that

$$lt_1(w_1, k) = rt_1(w_1, k).$$

Therefore, a contradiction has been obtained.

Similar speculations can be fulfilled in case of the assumption about the existence of such $w_1, w_2 \in Ls(B)$ that

$$l(w_1) > l(y_0),$$

$$l(w_2) < l(y_2),$$

$$z = (w_1 \equiv w_2).$$

That is why such $w_1$ and $w_2$ don't exist.

**Case 1b.** Let's assume, as before, that the string $z$ can be presented in the form $(y_0 \equiv y_2)$, where $y_0, y_2 \in D^+(B)$. Suppose also that there are such $q \in \{\wedge, \vee\}$, $m > 1$, and $w_1, \ldots, w_m \in Ls(B)$ that

$$z = (w_1 \, q \, w_2 \, q \ldots q \, w_m).$$

Obviously, $l(w_1) \neq l(y_2)$. Let $l(y_0) < l(w_1)$. Then the string $y_0 \equiv$ is a beginning of the string $w_1 \in Ls(B)$. Taking this into account, we easily receive a contradiction, repeating the speculations of the Case 1a.

If $l(w_1) < l(y_0)$, the string $w_1 \, q$ is a beginning of the string $y_0 \in Ls(B)$. In this case we again apply the Lemma 2 and the way of reasoning used in the process of considering Case 1a.

Therefore, if $z \in Ls(B)$ and for some $y_0, y_2 \in Ls(B)$, $z$ is a string of the form $(y_0 \equiv y_2)$, where $y_0, y_2 \in D^+(B,)$ then the string $z$ can't be obtained with the help of any rule (on the final step of inference) being different from the rule [3], and only from the "blocks" $y_0, y_2$.

**Case 1c.** Let there be such $q \in \{\wedge, \vee\}$, $m > 1$, and $y_1, \ldots, y_m \in Ls(B)$ that

$$z = (y_1 \, q \, y_2 \, q \ldots q \, y_m).$$

Then it is necessary to consider two situations:

1. there are such $u_1$, $u_2 \in Ls(B)$ that $z$ is the string of the form $(u_1 \equiv u_2)$;
2. there are such $p > 1$, $w_1, \ldots, w_p \in Ls(B)$, $d \in \{\wedge, \vee\}$ that

$$z = (w_1\, d\, w_2\, d\, \ldots\, d\, w_p),$$

besides, the $m+1$-tuple $(q, y_1, \ldots, y_m)$ is distinct from the $m+1$-tuple $(d, w_1, \ldots, w_p)$.

Consider the situation (1). Let $l(u_1) < l(y_1)$, then $u_1$, $y_1 \in Ls(B)$, and the string $u_1 \equiv$ is a beginning of the string $y_1$. This situation was analyzed in Case 1, where we obtained a contradiction.

If $l(y_1) < l(u_1)$, then $u_1$, $y_1 \in Ls(B)$, and the string $y_1\, q$ is a beginning of the string $u_1$; that is why, obviously, $l(y_1 q) < l(u_1)$.

Let's use the Lemma 2. Suppose that

$$y_1\, q = c_1 \ldots c_r\, c_{r+1},$$

where for $i = 1, \ldots, r+1$, $c_i \in D(B)$, $c_{r+1} = q$.

Since $c_{r+1}$ is the symbol $' \equiv '$, it follows from Lemma 2 that

$$lt_1(u_1, r+1) > rt_1(u_1, r+1).$$

But we have the relationships

$$lt_1(u_1, r+1) = lt_1(u_1, r) = lt_1(y_1, r),$$

$$rt_1(u_1, r+1) = rt_1(u_1, r) = rt_1(y_1, r).$$

But, since $y_1 \in Ls(B)$, it follows from Lemma 1 that

$$lt_1(y_1, r) = rt_1(y_1, r).$$

We have obtained a contradiction.

Let's analyze the situation (2). Suppose that $l(w_1) < l(y_1)$. Then $w_1, y_1 \in Ls(B)$, and the string $w_1 d$ is a beginning of $y_1$, where $d$ is one of the symbols $\wedge$, $\vee$. But in this case we are able to obtain a contradiction exactly in the same way as while analyzing the situation (1).

Obviously, the case $l(y_1) < l(w_1)$ is symmetric to the just considered case. Let's assume that $q = d$, and there is such $j$, $1 \leq j < m$ that

$$y_1 = w_1, \ldots, y_j = w_j,$$

but $w_{j+1} \neq y_{j+1}$. Then either the string $w_{j+1} d$ is a beginning of the string $y_{j+1}$ or $y_{j+1} d$ is a beginning of $w_{j+1}$. That is why we are in the situation considered above.

Thus, the analysis of the Case 1 has been finished. We have proved the following intermediary statement:

Let $B$ be an arbitrary conceptual basis, $z \in Ls(B)$ : $(X(B)\,) \cap V(B))$, and the first symbol of the string $z$ is the left parenthesis $'('$.

Then there is such unique $n+3$-tuple $(k, n, y_0, \ldots, y_n)$, where $1 \le k \le 10$, $n \ge 1$, $y_0, y_1, \ldots, y_n \in Ls(B)$ that

$$y_0 \,\&\, y_1 \,\&\, \ldots \,\&\, y_n \,\&\, z \in Lnr_{10}^k(B);$$

in this case, $k = 3$ or $k = 7$.

**Case 2.** Let $B$ be an arbitrary conceptual basis, $z$ be an arbitrary formula from $Ls(B)$
$: (X(B) \cup V(B))$, $1 \le k \le 10$, and $y_0, y_1, \ldots, y_n$ are such formulas from $Ls(B)$ that the relationship above takes place.

Suppose that $z$ has a beginning being a functional symbol, i.e., $z[1] \in F(B)$, and that the second before the end symbol $z$ is distinct from the symbol $':'$ . Then it immediately follows from the structure of the rules $P[0], P[1], \ldots\ldots, P[10]$ that the string $z$ is obtained as a result of applying the rule $P[2]$ at the last step of inference. That is why $z = f(y_1, \ldots, y_n)$, where $n \ge 1$, $y_1, \ldots, y_n \in Ls(B)$.

If $f \in F_1(B)$, i.e., $f$ is an unary functional symbol, then $n = 1$, and $y_1$ is unambiguously determined by $z$. Suppose that $n > 1$, $f \in F_n(B)$, and there is such a sequence $u_1, \ldots, u_n$ being distinct from the sequence $y_1, \ldots, y_n$ that $u_1, \ldots, u_n \in Ls(B)$, and string $(y_1, \ldots, y_n)$ coincides with the string $(u_1, \ldots, u_n)$.

Applying Lemma 2 similarly to the way of reasoning used while considering Case 1c, it is easy to show that the existence of two different representations $(y_1, \ldots, y_n)$ and $(u_1, \ldots, u_n)$ of the string $z \in Ls(B)$ is impossible due to the same reason as two different representations
$(y_1 \, d \, y_2 \, d \ldots d \, y_n)$ and $(u_1 \, d \, u_2 d \, \ldots \, d \, u_n)$, where $d \in \{\wedge, \vee\}$, are impossible.

**Case 3.** Let the assumptions of the formulation of the Theorem 4.5 be true for the conceptual basis $B$ and the string $z$; this string $z$ has the beginning $z[1]$ being a relational symbol, and $z[1]$ is not a functional symbol (that is, $z[1] \in R(B) \setminus F(B)$), and the second from the end symbol of the string $z$ is distinct from the symbol $':'$ . This situation is similar to the Case 2, only $z$ is constructed as a result of employing the rule $P[4]$ at the last step of inference.

That is why there exists the only (for $z$) such sequence $(k, n, y_0, \ldots, y_n)$ that $1 \le k \le 10$, $n \ge 1$,

$$y_0, y_1, \ldots, y_n \in Ls(B),$$

$$y_0 \,\&\, y_1 \,\&\, \ldots \,\&\, y_n \,\&\, z \in Ynr_{10}^k(B),$$

where $k = 4$.

**Case 4.** Let $B$ be an arbitrary conceptual basis, $z \in Ls(B)$ $setminus(X(B) \cup V(B))$, for $i = 1, \ldots, l(z)$, $z[i]$ the $i$-th symbol of the string $z$, $z[1] \in X(B)$, $z[2] = '*'$, the next to last symbol $z$ is distinct from the symbol $':'$. Then it directly follows from the rules $P[0], P[1], \ldots, P[10]$ that for constructing the string $z$, the rule $P[8]$ has been employed during the last step of inference. That is why there are such $p \ge 1$ and a sequence $(r_1, b_1, \ldots, r_p, b_p)$, where for $i = 1, \ldots, p$, $r_i \in R_2(B)$, $b_i \in Ls(B)$, that if $a = z[1]$, then

$$z = a * (r_1, b_1) \ldots (r_p, b_p).$$

We must now prove that for every $n+3$-tuple $(k, n, y_0, \ldots, y_n)$, such that $1 \leq k \leq 10$, $n \geq 1$, for $i = 0, \ldots, n$, $y_i \in Ls(B)$, it follows from the relationship

$$y_0 \,\&\, y_1 \,\&\, \ldots \,\&\, y_n \,\&\, z \in Ynr^k_{10}(B)$$

that the $n+3$-tuple $(k, n, y_0, \ldots, y_n)$ coincides with the tuple

$$(8,\, 2p+1,\, a,\, r_1,\, b_1, \ldots,\, r_p,\, b_p).$$

The relationship $z = a * (r_1, b_1) \ldots (r_p, b_p)$ implies that it is necessary to consider only the following situation: there are such

$$m \geq 1,\, h_1, \ldots, h_m \in R_2(B),\, d_1, \ldots, d_m \in Ls(B)$$

that

$$Z = a * (h_1, d_1) \ldots (h_m, d_m),$$

and this representation is distinct from the representation

$$z = a * (r_1, b_1) \ldots (r_p, b_p).$$

The elements $a, r_1, \ldots, r_p, h_1, \ldots, h_m$ are interpreted as symbols. That is why, obviously, $r_1 = h_1$.

Let $d_1 \neq b_1$ and $l(b_1) < l(d_1)$. Then the string $b_1)$ is a beginning of the string $d_1$. Using the Lemma 2 and Lemma 1 similar to the way of reasoning in the course of considering the Cases 1a and 1c, we obtain a contradiction. Therefore, $b_1 = d_1$.

Let there be such $i$ that $1 \leq i \leq minp, m$ and for $j = 1, \ldots, I$,

$$r_j = h_j,\, b_j = d_j,$$

$$r_{j+1} = h_{j+1},\, b_{j+1} \neq d_{j+1}.$$

Then it follows from $l(b_{j+1}) < l(d_{j+1})$ that the string $b_{j+1}$ is a beginning of the string $d_{j+1}$, but we've just analyzed a similar situation.

If $l(b_{j+1}) < l(d_{j+1})$, the string $(d_{j+1})$ is a beginning of the string $b_{j+1}$, and we encounter, in essence, the same situation. Therefore, the representations

$$z = a * (r_1, b_1) \ldots (r_p, b_p),$$

$$Z = a * (h_1, d_1) \ldots (h_m, d_m),$$

coincide.

**Case 5.** Suppose that for the conceptual basis $B$ and the string $z$, the assumptions of the formulation of the Theorem 3.5 are true, $z[1]$ is the quantifier $\forall$ or $\exists$, the symbol $z[n-1] \neq ':'$, where $n = Length(z)$. Then, obviously, the rule $P[9]$ was applied at the last step of building the string $Z$. . That is why $z$ is the string of the form

$$Q\, var\, (conc)\, A\,,$$

where $Q = z[1]$, $var \in V(B)$, $conc, A \in Ls(B)$, $conc \in X(B)$ or $conc$ is such a string that for constructing it, the rule $P[8]$ was applied at the last step of inference, and $A \,\&\, P \in Ts(B)$, where $P$ is the sort "a meaning of proposition" of the basis $B$.

Let $l(z) = m$ (that is, $m$ is the length of $z$). If $conc \in X(B)$, then the uniqueness of the representation of $z$ is obvious:

$$Q = z[1],\ v = z[2],\ '(' = z[3],$$

$$conc = z[4],\ ')' = z[5],\ A = z[6] \ldots z[m].$$

If $conc \in Ls(B) \setminus (X(B) \cup V(B))$, then let's use the Lemma 1.

Let $l(conc) = p$, where $p > 1$ then for $i = 1, \ldots, p$,

$$lt_1(conc, i) \geq rt_1(conc, i);$$

$$lt_1(conc, p) = rt_1(conc, p).$$

That is why for $q = 1, \ldots, p+3$,

$$lt_1(z, q) > rt_1(z, q),$$

$$lt_1(z, p+4) = rt_1(z, p+4).$$

Therefore, the position of the right parenthesis $')'$ immediately after the string $conc$ can be defined as such minimal integer $s\ leq\, 1$ that

$$lt_1(z, s) > rt_1(z, s),$$

$$lt_1(z, s) = rt_1(z, s).$$

That is why, if $z \in Ls(B)$ and $z[1]$ is the quantifier $Q$, where $Q = \forall$ or $Q = \exists$, then there exists the only such $n+3$-tuple $(k, n, y_0, \ldots, y_n)$, where $1 \leq k \leq 10$, $n \geq 1$, $y_0, y_1, \ldots, y_n \in Ls(B)$, that

$$y_0 \,\&\, y_1 \,\&\, \ldots \,\&\, y_n \,\&\, z \in Ynr_{10}^{k}(B);$$

besides, $k = 9$, $n = 4$, $y_0 = Q$, $y_1 = v$, $y_3 = conc$, $y_4 = A$ (with respect to the relationship $z = Q\, var\, (conc)\, A$.

**Case 6.** Suppose that the assumptions of the formulation of the Theorem 3.5 are true for the conceptual basis $B$ and the string $z$, $z[1] = '\langle'$, and the next to last symbol $z$ is distinct from ':' (colon). Then, obviously, the rule $P[10[$ was used at the last step of constructing $z$. Assume that there exists such sequence $m, u_1, \ldots, u_n$ and a different sequence $n, y_1, \ldots, y_n$, where $m, n \geq 1$, $u_1, \ldots, u_m, y_1, \ldots, y_n \in Ls(B)$, that $z$ can be represented in two forms

$$\langle u_1, \ldots, u_m \rangle,$$

$$langle y_1, \ldots, y_n \rangle.$$

Applying Lemma 2 similar to the way of reasoning in Case 2, we conclude that two different representations of $z$ are impossible due to the same reason as the impossibility of two different representations $f(u_1,\ldots,u_m)$ and $f(y_1,\ldots,y_n)$ of the same string from $Ls(B)$.

**Case 7.** Let the assumptions of the Theorem 4.5 be true for the conceptual basis $B$ and the string $z$, $z[1]$ be an intensional quantifier from $Int(B)$, $z$ has no ending of the form : $v$, where $v \in V(B)$, $m = l(z)$. Then, obviously, $z$ can be obtained with the help of the rule with the number $k = 1$ out of the "blocks" $y_1 = z[1]$ and $y_2 = z[2] \in z[m]$.

**Case 8.** Let $B$ be an arbitrary conceptual basis, $z \in Ls(B) \setminus (X(B) \setminus V(B))$, $z[1] = \neg$. Then there is such string $y \in Ls(B)$ that $z = \neg y$. The analysis of the structure of the rules $P[0], P[1], \ldots, P[10]$ shows that only two situations are possible: (1) $y$ has no ending : $v$, where $v \in V(B)$, that is why $z$ was constructed out of the pair $(\neg, y)$ as a result of employing the rule $P[6]$; (2) $y = w : v$, where $v \in V(B)$; in this case, $z$ was built out of the pair of operands $(\neg w, v)$ by applying one time the rule $P[5]$.

Let's pay attention to the fact that the situation when $z$ was constructed out of the pair of operands $(\neg, w : v)$ by means of applying the rule $P[6]$, is impossible; the reason is that the rule $P[6]$ allows for constructing the expressions of the form $\neg a$ only in case when either $a\ inX(B)$ or no one of the rules $P[2], P[5], P[10]$ was employed at the last step of constructing the string $a$.

**Case 9.** Let $B$ be an arbitrary conceptual basis, $z \in Ls(B) \setminus (X(B) \cup V(B))$, $z$ has an ending being the substring of the form : $var$, where $var \in V(B)$, and $z$ has no beginning $'\neg'$. Let's show that in this case the rule $P[5]$ was applied at the last step of obtaining the string $a$.

Assume that it is not true, and the rule $P_m$, where $1 \leq m \leq 10$, $m\ neq 5$, $m \neq 6$. was used at the last step of constructing the string $a$. If $m = 1$, then $z = qtr\,des$, where $q$ is an intensional quantifier from $Int(B)$, $des \in X(B)$ or

$$des = cpt * (r_1, b_1) \ldots (r_p, b_p),$$

where $p \geq 1$, $a \in X(B)$, $r_1, \ldots, r_n \in R(B)$, $b_1, \ldots, b_p \in Ls(B)$.

Since $z$ has an ending being the substring of the form : $var$, where $var \in V(B)$, then the situation $z = qtr\,des$, where $q \in Int(B)$, $des \in X(B)$, is excluded. But $v \neq ')'$; therefore, we obtain a contradiction, and the situation $m = 1$ is impossible. If $m$ is one of the integers 2, 3, 4, 7, 8, the last symbol of $z$ is the right parenthesis $')'$. That is why each of these situations is impossible. If $m = 10$, the last symbol of $z$ is $'\rangle'$, and it is impossible too.

Suppose that the rule $P[9]$ was applied at the last step of inference. Then there are such

$$qex \in \{\exists, \forall\},\ var \in V(B),\ des \in Ls(B),\ A \in Ls(B),$$

that $z = qex\,var\,(des)\,A$.

According to the definition of the rule $P[9]$, the string $A$ has no ending of the form : $z$ , where $z$ is an arbitrary variable from $V(B)$. That is why in Case 9, the rule $P[5]$ was applied at the last step of constructing $z$. Thus, we've considered all possible cases, and Theorem 4.5 is proved.

# Glossary

**c.b.** conceptual basis

**CIA** Computer Intelligent Agent

**CMR** Component-Morphological Representation of an NL-text

**DRT** Discourse Representation Theory

**e-Commerce** Electronic Commerce

**e-Contracting** Electronic Contracting

**e-Negotiations** Electronic Negotiations

**e-Science** Electronic Science

**EL** Episodic Logic

**FIPA** Foundation for Intelligent Physical Agents

**IFS** Integral Formal Semantics of Natural Language

**K-calculus** Knowledge Calculus

**KCL-theory** Theory of K-calculuses and K-languages

**l.b.** linguistic basis

**LP** Linguistic Processor

**MAS** Multi-Agent System (or Systems)

**m.c.b.** marked-up conceptual basis

**MR** Morphological Representation of an NL-text

**MSSR** Matrix Semantic-Syntactic Representation of an NL-text

**NL** Natural Language

**NLPS** Natural Language Processing System

**NLPSs** Natural Language Processing Systems

**OWL** Ontology Web Language

**SCL-theory** Theory of S-calculuses and S-languages

**SK-language** Standard Knowledge Language

**SR** Semantic Representation of an NL-text

**TCG** Theory of Conceptual Graphs

**UNL** Universal Networking Language

**USR** Underspecified Semantic Representation of an NL-text

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# Index