Finite convergent presentation of plactic monoid for

type C

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To cite this version:
Nohra Hage. Finite convergent presentation of plactic monoid for type C. 2014. <hal-01174477>
Abstract – We give an explicit presentation for the plactic monoid for type C using admissible column generators. Thanks to the combinatorial properties of symplectic tableaux, we prove that this presentation is finite and convergent. We obtain as a corollary that plactic monoids for type C satisfy homological finiteness properties.

Keywords – Plactic monoid, crystal graphs, symplectic tableau, convergent presentations.
1. Introduction

The plactic monoid was discovered by Knuth, [Knu70], using the tableau defined by Schensted in [Sch61] in his study of the longest increasing subsequence of a permutation. Lascoux and Schützenberger in [LS81] used it in order to give a proof of the Littlewood-Richardson rule for the decomposition of tensor products of irreducible modules on the Lie algebra of traceless square matrices.

Thanks to Kashiwara’s theory of crystal bases [Kas91, KN94, Kas95], plactic monoid can be defined for all classical simple Lie algebras extending the previous definition in the case of type A. Plactic monoid for type C was described by Lascoux, Leclerc and Thibon without proof in [LLT95]. After Lecouvey in [Lec02] and Baker in [Bak00] defined it by different methods. For types B and D, the plactic monoid was introduced by Lecouvey in [Lec03].

For type A, consider the ordered alphabet \( A_n = \{1 < 2 < \cdots < n\} \). For every word \( w \) over the free monoid \( A^*_n \), a unique tableau \( P(w) \) can be computed using the Schensted insertion algorithm (column insertion) [Sch61]. Let \( u \) and \( v \) be two words on \( A^*_n \), one can define a relation \( \sim \) on the free monoid \( A^*_n \) by:

\[ u \sim v \text{ if, and only if, } P(u) = P(v). \]

Then the quotient \( \text{Pl}(A) := A^*_n/\sim \) is called the plactic monoid for type A. The plactic monoid can be also described as the quotient of \( A^*_n \) by the Knuth relations:

\[
\{ xzy = zxy \mid 1 \leq x < y < z \leq n \} \cup \{ yxz = yzx \mid 1 \leq y < z \leq n \}
\]

which is called the Knuth presentation.

We deal with presentations from the rewriting theory perspective. In this context, relations are oriented and are considered as rewriting steps. A presentation terminates if it has no infinite rewriting sequence. A terminating presentation is convergent if every element admits a unique normal form. Having a finite convergent presentation of a monoid has many advantages: computation of normal form and some homological properties. An open problem was to find a finite convergent presentation of the plactic monoid.

In [CGM15], Cain, Gray and Malheiro answer positively this question. They constructed a finite presentation of the plactic monoid for type A by introducing the column generators. They proved the convergence of this presentation using the combinatorial properties of Young tableaux. But the above question was still open for the plactic monoids for the others types.

In the present work, we consider the plactic monoid for type C constructed by Lecouvey in [Lec02]. Our aim is to construct a finite convergent presentation for this monoid. The generating set of this presentation contains the finite set of admissible columns introduced by Kashiwara and Nakashima in [KN94]. As a corollary, we deduce that plactic monoids for type C satisfy some homological finiteness properties.

The paper is organised as follows. We first recall in section 2 some properties of 2-polygraph which corresponds to a presentation of a monoid by a rewriting system, that is a presentation by generators and oriented relations. After that, we present some properties of crystal graphs. In section 3 we present the definitions and some properties of admissible columns and symplectic tableaux. We describe the column insertion algorithm for type C introduced by Lecouvey in [Lec02] and a definition of the Plactic monoid for type C. In section 4, we give a finite and convergent presentation of the plactic monoid for type C using admissible column generators.
2. Preliminaries

2.1. Rewriting properties of 2-polygraphs

We will give some rewriting properties of the presentations of monoids. These presentations are discussed in terms of polygraphs in [GM14]. A 2-polygraph is a triple \( \Sigma = (\Sigma_0, \Sigma_1, \Sigma_2) \) made of an oriented graph

\[
\begin{array}{c}
\Sigma_0 \xrightarrow{s_0} \Sigma_1 \\
\xleftarrow{t_0}
\end{array}
\]

where \( \Sigma_0 \) and \( \Sigma_1 \) are respectively the sets of objects, or generating 0-cells and of arrows, or generating 1-cells and \( s_0, t_0 \) denote the source and target maps. The set \( \Sigma_2 \) is a cellular extension over the free category \( \Sigma_1^* \), that is a set of 2-cells relating parallel 1-cells

\[
\begin{array}{c}
s_1(\alpha) \\
\xleftarrow{x} \alpha \xrightarrow{\downarrow} y \\
\xleftarrow{t_1(\alpha)}
\end{array}
\]

such that \( s_0s_1(\alpha) = s_0t_1(\alpha) \) and \( t_0s_1(\alpha) = t_0t_1(\alpha) \), where \( s_1(\alpha), t_1(\alpha) \in \Sigma_1^* \). In our case, the set \( \Sigma_0 \) contains only one 0-cell. In the sequel, a 2-polygraph is denoted by \( \Sigma = (\Sigma_1, \Sigma_2) \).

A monoid \( M \) is presented by a 2-polygraph \( \Sigma \) if \( M \) is isomorphic to the quotient of the free monoid \( \Sigma_1^* \) by the congruence generated by \( \Sigma_2 \). Then the generating 1-cells are the generators of \( M \) and the generating 2-cells correspond to the relations of \( M \). Note that we will also say words for the 1-cells of \( \Sigma_1^* \) in a case of monoid.

A 2-polygraph \( \Sigma \) is finite if \( \Sigma_1 \) and \( \Sigma_2 \) are finite. For two 1-cells \( u \) and \( v \), we write \( u \Rightarrow v \) for a 2-cell in \( \Sigma_2 \). Denote by \(|w|\) the length of a word \( w \) on \( \Sigma_1^* \). A rewriting step of \( \Sigma \) is a 2-cell with shape

\[
\begin{array}{c}
x \xrightarrow{w} y \xleftarrow{\downarrow \varphi} z \xrightarrow{w'} t
\end{array}
\]

where \( \varphi \) is a 2-cell and \( w \) and \( w' \) are 1-cells of \( \Sigma_1^* \). A rewriting sequence of \( \Sigma \) is a finite or infinite sequence of rewriting steps. We say that \( u \) rewrites into \( v \) if \( \Sigma \) has a nonempty rewriting sequence from \( u \) to \( v \). A 1-cell of \( \Sigma_1^* \) is a normal form if \( \Sigma \) has no rewriting step with source \( u \). A normal form of \( u \) is a 1-cell \( v \) that is a normal form and such that \( u \) rewrites into \( v \). We say that \( \Sigma \) terminates if it has no infinite rewriting sequences. We say that \( \Sigma \) is confluent if for any 1-cells \( u, u' \) and \( u'' \) of \( \Sigma_1^* \), such that \( u \) rewrites into \( u' \) and \( u'' \), there exists a 1-cell \( v \) such that \( u' \) and \( u'' \) rewrite into \( v \). We say that \( \Sigma \) is convergent if it terminates and it is confluent. Note that a terminating 2-polygraph is convergent if every 1-cell admits a unique normal form.

Two 2-polygraphs are Tietze-equivalent if they present the same monoid. Two finite 2-polygraphs are Tietze-equivalent if, and only if, they are related by a finite sequence of elementary Tietze transformations:
2. Preliminaries

- adjunction or elimination of a 1-cell $x$ and of a 2-cell $\alpha : u \Rightarrow x$, where $u$ is a 1-cell of the $(\Sigma_I \setminus \{x\})^*$.
- adjunction or elimination of a 2-cell $\alpha : u \Rightarrow v$ such that $u$ and $v$ are related by a nonoriented sequence of 2-cells all in $\Sigma_2 \setminus \{\alpha\}$.

2.2. Crystal graphs

The symplectic Lie algebra $sp_{2n}$ is the Lie algebra of $2n$ by $2n$ matrices $A$, for $n > 0$, that satisfy

$$\Omega A + A^T \Omega = 0,$$

where $A^T$ is the transpose of $A$ and $\Omega = \begin{pmatrix} 0 & I_n \\ -I_n & 0 \end{pmatrix}$.

Let $V_n$ be the vector representation of $sp_{2n}$, this representation is of dimension $2n$ and we index a basis of $V_n$ by the set

$$C_n = \{1, 2, \ldots, n, \bar{n}, \ldots, \bar{1}\},$$

totally ordered by $1 < 2 < \cdots < n < \bar{n} < \cdots < \bar{1}$. Denote by $C_n^*$ the free monoid over $C_n$.

Crystal graphs are oriented graphs with labelled arrows. An arrow $a \xrightarrow{i} b$ means that $\tilde{f}_i(a) = b$ and $\tilde{e}_i(b) = a$, where $\tilde{e}_i$ and $\tilde{f}_i$ are the crystal graph operators that we will define later in our context. Note that every representation of $sp_{2n}$ admits a crystal graph. The crystal graph of $V_n$ is:

$$1 \xrightarrow{1} 2 \xrightarrow{2} \cdots \xrightarrow{n-1} n \xrightarrow{n} \bar{n} \xrightarrow{n-1} \cdots \xrightarrow{2} \bar{1} \Rightarrow \bar{1}.$$

Now, we consider tensor products of the vector representations $V_n^\otimes l$, for any $l$ and the infinite dimensional representation $\bigoplus V_n^\otimes l$. The crystal graphs of these representations are denoted by $G_{n,l}$ and $G_n$ respectively. The vertices of $G_n$ are indexed by the words of $C_n^*$ and those of $G_{n,l}$ by the words of length $l$.

In [KN94], Kashiwara and Nakashima describe a process to compute the action of the crystal operators $\tilde{e}_i$ and $\tilde{f}_i$ on a word $w$ of $C_n^*$, for a fixed $i$. First, one considers the subword $w_l$ of $w$ which contains only the letters $i, i+1, \bar{i+1}$ and $\bar{i}$. One identifies the letters $i$ and $\bar{i}$ by the symbol $+$ and the letters $i+1$ and $\bar{i}$ by the symbol $\bar{+}$. Secondly, we remove the subwords of length 2 in $w_l$ which correspond to the symbol $+-$, i.e., we remove adjacent letters $(i, i+1), (i, \bar{i}), (\bar{i+1}, i+1)$ and $(\bar{i+1}, \bar{i})$. Then one obtains a new subword $w^{(1)}_l$ of $w$. The second step of the process is repeated until there is no possibility to remove new letters. Let $r$ and $s$ be respectively the number of letters corresponding to the symbol $-$ and $+$ in the final subword.

- If $r > 0$ then $\tilde{e}_i(w)$ is obtained by replacing in $w$ the rightmost element with the symbol $-$ of the final subword, by its corresponding element with the symbol $+, i.e., i+1$ is transformed into $i$ or $\bar{i}$ into $\bar{i}+1$, and the others elements of $w$ stay unchanged. If $r = 0$, then $\tilde{e}_i(w) = 0$.

- If $s > 0$ then $\tilde{f}_i(w)$ is obtained by replacing in $w$ the rightmost element with the symbol $+$ of the final subword, by its corresponding element with the symbol $-, i.e., i$ is transformed into $i + 1$ or $\bar{i}+1$ into $\bar{i}$, and the others elements of $w$ stay unchanged. If $s = 0$, then $\tilde{f}_i(w) = 0$.
**2.2.1. Example.** Consider the word \( w = \overline{3323133} \). Let us compute \( \tilde{e}_i(w) \) and \( \tilde{f}_i(w) \) for \( i = 2 \). We have

\[
\begin{align*}
\tilde{e}_i(w) &= \overline{332333}, \\
\tilde{f}_i(w) &= \overline{3323133}.
\end{align*}
\]

We remark that we cannot remove new letters from \( w_{(1)} \), then \( r = s = 1 \) and we obtain

\[
\begin{align*}
\tilde{e}_2(w) &= \overline{3323123}, \\
\tilde{f}_2(w) &= \overline{3323132}.
\end{align*}
\]

Thanks to the properties of crystal operators with regards to the tensor products, the crystal graph \( G_{n,l} \) can be decomposed into connected components. They correspond to the crystal graphs of the irreducible representations occurring in the decomposition of \( V_n^{\otimes l} \). If \( w \) is a vertex of \( G_{n,l} \), the connected component of \( G_{n,l} \) containing \( w \) is denoted by \( B(w) \). In each connected component, there exists a unique vertex \( w^0 \) which satisfies the following property:

\[
\tilde{e}_i(w^0) = 0, \text{ for } i = 1, \ldots, n.
\]

This vertex is called the **vertex of highest weight**, and its weight is

\[
\text{wt}(w^0) = d_n \Lambda_n + \sum_{i=1}^{n-1} (d_i - d_{i+1}) \Lambda_i,
\]

where \( d_i \) is the number of letters \( i \) in \( w^0 \) minus the number of letters \( \overline{i} \), and \( \Lambda_1, \ldots, \Lambda_n \) are the fundamental weights of \( \mathfrak{sp}_{2n} \). Recall that two connected components are isomorphic if their vertex of highest weight has the same weight.

A **Young diagram** is a collection of boxes in left-justified rows, where each row has the same or shorter length than the one above it. The irreducible \( \mathfrak{sp}_{2n} \)-modules can be parameterized by Young diagrams. One associates to \( \lambda = \sum_{i=1}^{n} \lambda_i \Lambda_i \) the Young diagram containing \( \lambda_i \) columns of height \( i \). We say that this Young diagram has shape \( \lambda \). The number of boxes of it is equal to \( |\lambda| = \sum_{i=1}^{n} \lambda_i \). Denote by \( B(\lambda) \) the crystal graph of the irreducible module of highest weight \( \lambda \).

**2.2.2. Lemma ([KN94]).** For any words \( u \) and \( v \) on \( C_n^* \), the word \( uv \) is a vertex of highest weight of a connected component of \( G_n \) if, and only if, \( u \) is a vertex of highest weight and \( \epsilon_i(v) \leq \phi_i(u) \) for any \( i = 1, \ldots, n \), where

\[
\begin{align*}
\epsilon_i(w) &= \max\{k; \tilde{e}_k^i(w) \neq 0\} \text{ and } \phi_i(w) = \max\{k; \tilde{f}_k^i(w) \neq 0\}.
\end{align*}
\]

for \( w \) a word on \( C_n^* \).

For more details about crystal graphs, the reader is referred to [Kas91, Kas95, KN94].

### 3. Plactic monoid for type C

#### 3.1. Symplectic Tableaux
A column for type C is a Young diagram $C$ consisting of one column filled by letters of $C_n$ strictly increasing from top to bottom. Denote by $w(C)$ the word obtained by reading the letters of a column $C$ from top to bottom. It is called the reading of $C$. The height of a column $C$ is the number of letters in $C$ and denoted by $h(C)$. A word $w$ is a column word if there exists a column $C$ such that $w = w(C)$.

For example the Young diagram

$$
C = \begin{array}{cccc}
1 \\
2 \\
3 \\
6 \\
5 \\
\end{array}
$$

is a column. Its reading is $w(C) = 12356$.

In [KN94], Kashiwara and Nakashima introduce the notion of admissible column. Let $w(C) = x_1 \cdots x_{h(C)}$ be the reading of a column $C$. For us, the column $C$ is admissible if for $m = 1, \cdots, h(C)$, the number of letters $x$ in $C$ such that $x \leq m$ or $x \geq m$ is smaller or equal than $m$.

Let $C$ be a column and $I = \{x_1 > \cdots > x_r\}$ be the set of unbarred letters such that the pair $(x_i, x_i)$ occurs in $C$, for $i = 1, \cdots, r$. The column $C$ can be split if there exists a set of unbarred letters $J = \{y_1 > \cdots > y_r\}$ which contains $r$ elements of $C_n$ such that:

- $y_1$ is the greatest letter of $C_n$ satisfying $y_1 < x_1, y_1 \notin C$, and $y_1 \notin C$,
- for $i = 2, \cdots, r$, $y_i$ is the greatest letter of $C_n$ such that $y_i < \min(y_{i-1}, x_i), y_i \notin C$ and $y_i \notin C$.

Denote by $rC$ the column obtained by changing in $C, x_i$ into $y_i$ for each letter $x_i$ in the set $I$ up to reordering. Denote by $lC$ the column obtained by changing in $C, x_i$ into $y_i$ for each letter $x_i$ in the set $I$ up to reordering.

3.1.1. Proposition ([She99]). A column $C$ is admissible if, and only if, it can be split.

3.1.2. Example. Let $w(C) = 2568528$ be the reading of a column $C$. Then

$I = \{8 > 5 > 2\}, J = \{7 > 4 > 1\}, rC = 25685241, \text{ and } lC = 14678523.$

The column $C$ can be split, then it is an admissible column.

3.1.3. Example. Let $w(C') = 2346732$ be the reading of a column $C'$. Then

$I = \{6, 3, 2\}, y_1 = 5, y_2 = 1,$

and we cannot find an element $y_3$ of $C_n$ such that $y_3 < 1$. Thus $C'$ cannot be split.

Using admissible columns, one can construct a tableau whose columns are admissible with an additional property on them. This tableau is called the symplectic tableau. We will recall its definition in our context.

Let $C_1$ and $C_2$ be two admissible columns. We consider the following notation :

- $C_1 \leq C_2$ if $h(C_1) \geq h(C_2)$ and the rows of the tableau $C_1C_2$ are weakly increasing from left to right.
3.2. Definition of the plactic monoid for type C

Consider a tableau $T = C_1 \cdots C_r$ with admissible columns $C_i$, for $i = 1, \ldots, r$. The tableau $T$ is a symplectic tableau if $C_i \leq C_{i+1}$ for $i = 1, \ldots, r - 1$. The reading of the symplectic tableau $T$ is the word $w(T)$ obtained by reading the columns of $T$ from right to left, that is

\[ w(T) = w(C_r)w(C_{r-1}) \cdots w(C_1). \]

3.1.4. Example. Let us consider the tableau

\[
\begin{array}{ccc}
1 & 2 & 3 \\
2 & 3 & 1 \\
3 & 2 & \\
\end{array}
\]

$T$ is a symplectic tableau. Indeed,

- $w(C_1) = 123, I_{C_1} = J_{C_1} = \emptyset$, and $r_{C_1} = 1C_1 = 123$.
- $w(C_2) = 23 \bar{2}, I_{C_2} = (2), J_{C_2} = (1), r_{C_2} = 23 \bar{2}$, and $1C_2 = 13 \bar{2}$.
- $w(C_3) = 3, I_{C_3} = J_{C_3} = \emptyset$, and $r_{C_3} = 1C_3 = 3$.

The columns $C_1$, $C_2$, and $C_3$ can be split, then they are admissible columns. We have also $C_1 \leq C_2 \leq C_3$, then $T$ is a symplectic tableau and $w(T) = 323 \bar{1}2123$.

Let $\lambda = \sum_{i=1}^{n} \lambda_i / \lambda_i$ be a weight with $\lambda_i \geq 0$. By Theorem 4.5.1 in [KN94], $B(\lambda)$ coincides with the set of symplectic tableaux of shape $\lambda$. More precisely, the readings of these tableaux are the vertices of a connected component of $G_{n,\lambda}$ isomorphic to $B(\lambda)$. The highest weight vertex of this component is the reading of the tableau of shape $\lambda$ filled with 1 on the 1st row, 2 on the 2nd row, ..., and $n$ on the $n$th row.

3.2. Definition of the plactic monoid for type C

Let $u$ and $v$ be two words on $C_n^*$. One can define a relation $\sim$ on the free monoid $C_n^*$ by $u \sim v$ if, and only if, $u$ and $v$ have the same position in their isomorphic connected component $B(u)$ and $B(v)$ of the crystal $G_n$. In other words, there exist $i_1, \ldots, i_r$ such that $u = f_{i_1} \cdots f_{i_r}(u^0)$ and $v = f_{i_1} \cdots f_{i_r}(v^0)$.

3.2.1. Proposition ([Lec02, Proposition 3.1.2]). Every word $w$ on $C_n^*$ admits a unique symplectic tableau $T$ such that $w \sim w(T)$. The Tableau $T$ is denoted by $P(w)$.

The quotient $P(C) := C_n^*/\sim$ is called the plactic monoid for type $C$ or the symplectic plactic monoid.

Furthermore, the plactic monoid for type $C$ can be presented by generators and relations. Consider the congruence $\equiv$ generated by the following relations on $C_n^*$:

\begin{align*}
(R_1) & : \begin{cases} 
yxz \equiv yxz & \text{for } x \leq y < z \text{ with } z \neq \overline{x} 
xzy \equiv zxy & \text{for } x < y \leq z \text{ with } z \neq \overline{x} \end{cases} \\
(R_2) & : \begin{cases} 
y(x-1)(x-1) \equiv yx & \text{for } 1 < x \leq n \text{ and } x \leq y \leq \overline{x} 
x\overline{xy} \equiv [x-1][x-1]y & \text{for } 1 < x \leq n \text{ and } x < y \leq \overline{x} \end{cases} \\
(R_3) & : \text{let } w \text{ be a nonadmissible column word such that each strict factor of } w \text{ is an admissible column word. Let } z \text{ be the lowest unbarred letter such that the pair } (z, z) \text{ occurs in } w \text{ and } N(z) = \overline{z} + 1. \text{ Then } w \equiv \tilde{w}, \text{ where } \tilde{w} \text{ is the column word obtained by erasing the pair } (z, z) \text{ in } w. \end{align*}
3.2.2. Remark. The relations (R_1) contain the Knuth relations for type A. The relations (R_3) are called the contraction relations.

3.2.3. Theorem ([Lec02, Theorem 3.2.8]). For any words u and v on C_n^*, we have

\[ u \sim v \text{ if, and only if, } u \equiv v \text{ if, and only if, } P(u) = P(v). \]

3.3. A bumping algorithm for type C

In [Sch61], Schensted introduces an insertion algorithm (column insertion) to compute a unique tableau \( P(w) \) for a word \( w \) over the alphabet \( A_n = \{1 < \cdots < n\} \). The column insertion procedure inserts a letter \( x \) into a tableau \( T \) as follows. Let \( y \) be the smallest element of the first column of the tableau \( T \) such that \( y \geq x \). Then \( x \) replaces \( y \) in the first column and \( y \) is bumped into the next column where the process is repeated. This procedure terminates when the letter which is bumped is greater than all the elements of the next column. Then it is placed at the bottom of that column. Hence the tableau \( P(w) \) can be computed by starting with the empty word, which is a valid tableau, and iteratively applying Schensted’s algorithm.

In [Lec02], Lecouvey introduces an insertion scheme to compute the symplectic tableau \( P(w) \) analogous to the Schensted’s algorithm for type A. The insertion of a letter \( x \) in a symplectic tableau \( T \) is denoted by \( x \to T \).

3.3.1. Insertion of a letter in an admissible column. Consider a word \( w = w(C)x \), where \( x \) is a letter and \( C \) is an admissible column of height \( p \). We have three cases:

- If \( w \) is the reading of an admissible column, then \( x \to C \) is the column obtained by adding a box filled by the letter \( x \) at the bottom of \( C \). In this case, the highest weight vertex of \( B(w) \) is equal to \( 1 \cdots p(p + 1) \).

- If \( w \) is a nonadmissible column word such that each strict factor of it is admissible, then \( x \to C \) is the column of reading \( \tilde{w} \) obtained from \( w \) by applying relation of type \( (R_3) \). In this case, the highest weight vertex of \( B(w) \) is equal to \( 1 \cdots p^2 \).

- If \( w \) is not a column word, then \( x \to C \) is obtained by applying relations of type \( (R_1) \) or \( (R_2) \) to the final subword of length 3 of \( w \). On the resulting word, one continues by applying relations of type \( (R_1) \) or \( (R_2) \) to the maximal overlapping subword of length 3 to the left and this procedure is repeated until the first subword of length 3 has been operated. The result is the reading of a symplectic tableau consisting of a column \( C' \) of height \( p \) and a column \( x' \), where \( x' \) is an element of \( C_n \). Then

\[ x \to C = C' \begin{bmatrix} x' \end{bmatrix} = P(w). \]

In this case, the highest weight vertex of \( B(w) \) is equal to \( 1 \cdots p^2 \).

3.3.2. Example. 1. Suppose \( w(C) = 36^74 \) and \( x = \overline{3} \), then

\[
\begin{array}{c}
3 \\
6 \\
\overline{6} \\
4
\end{array} \to \begin{array}{c}
\overline{3} \\
6 \\
\overline{6} \\
4 \\
3
\end{array} = \begin{array}{c}
3 \\
6 \\
6 \\
4 \\
3
\end{array}
\]
3.3. A bumping algorithm for type C

2. Suppose \( w(C) = 14\overline{3} \) and \( x = \overline{2} \), the word \( 14\overline{3}\overline{2} \) is a nonadmissible column word such that each strict subword of which is an admissible column word, then we obtain by applying relation of type \((R_3)\),

\[
\begin{array}{c|c}
 1 & 1 \\
 4 & 4 \\
\hline
 3 & 2 \\
\end{array}
\]

3. Suppose \( w(C) = 14\overline{3} \) and \( x = 2 \), then the word \( 14\overline{3}2 \) is not a column word. By applying relations of type \((R_1)\) or \((R_2)\), we obtain:

\[
14\overline{3}2 \equiv 142\overline{3} \equiv 1423 \equiv 412\overline{3}.
\]

Then

\[
\begin{array}{c|c}
 1 & 1 \\
 4 & 2 \\
\hline
 3 & 3 \\
\end{array}
\]

3.3.3. Insertion of a letter in a symplectic tableau. Let \( T = C_1 \cdots C_r \) be a symplectic tableau with admissible column \( C_i \), for \( i = 1, \cdots, r \), and \( x \) be a letter.

1. If \( w(C_1)x \) is an admissible column word, then \( x \rightarrow T \) is the tableau obtained by adding a box filled by \( x \) on the bottom of \( C_1 \).

2. If \( w(C_1)x \) is a nonadmissible column word such that each strict factor of it is an admissible column word. Let \( w(C_1)x = y_1 \cdots y_s \) be the admissible column word obtained from \( w(C_1)x \) by applying relation of type \((R_3)\) and \( \hat{T} = C_2 \cdots C_r \) be the tableau obtained from \( T \) after eliminating the first column \( C_1 \). Then \( x \rightarrow T \) is obtained by inserting successively the elements of \( w(C_1)x \) in the tableau \( \hat{T} \). That is,

\[
x \rightarrow T = y_s \rightarrow (y_{s-1} \rightarrow (\cdots y_1 \rightarrow \hat{T})).
\]

Moreover, the insertion of \( y_1, \cdots, y_s \) in \( \hat{T} \) does not cause a new contraction.

3. If \( w(C_1)x \) is not a column word, then

\[
x \rightarrow C_1 = \begin{array}{c}
 1 \\
 4 \\
\hline
 3 \\
\end{array} \begin{array}{c}
 y \\
 2 \\
\hline
 3 \\
\end{array}
\]

where \( C'_1 \) is an admissible column of height \( h(C_1) \) and \( y \) a letter. Then

\[
x \rightarrow T = C'_1(y \rightarrow C_2 \cdots C_r),
\]

that is, \( x \rightarrow T \) is the juxtaposition of \( C'_1 \) with the tableau obtained by inserting \( y \) in the tableau \( C_2 \cdots C_r \).
3. Plactic monoid for type C

3.3.4. Example. Consider a symplectic tableau

\[ T_1 = \begin{array}{ccc}
1 & 2 & 3 \\
2 & 3 & \\
3 & 2 & 
\end{array} \]

and a letter \( x = 1 \). Let us compute \( x \rightarrow T_1 \). First, we begin inserting \( x \) in the first column \( C_1 \) of \( T_1 \). The word 1231 is not a column word, then by applying at each step \((R_1)\) or \((R_2)\), we obtain:

\[ 1231 \equiv 1213 \equiv 1123, \]

so

\[ 1 \rightarrow \begin{array}{ccc}
1 & \\
2 & \\
3 & 
\end{array} \begin{array}{ccc}
1 & 1 & \\
2 & 2 & \\
3 & 3 & 
\end{array} \]

Then \( 1 \rightarrow T_1 = C_1'(1 \rightarrow T_2') \), where

\[ C_1' = \begin{array}{c}
1 \\
2 \\
3 
\end{array} \quad \text{and} \quad T_2' = \begin{array}{c}
2 \\
3 \\
4 
\end{array} \]

Similarly, we have \( 2 \rightarrow 3 \equiv 231 \equiv 213 \), then

\[ 1 \rightarrow \begin{array}{ccc}
2 & \\
3 & \\
2 & 
\end{array} \begin{array}{ccc}
1 & 2 & \\
3 & 3 & \\
2 & 2 & 
\end{array} \]

So \( 1 \rightarrow T_1 = C_1'C_2'(2 \rightarrow 3) \), where

\[ C_2' = \begin{array}{c}
1 \\
2 \\
3 
\end{array} \]

Finally, we have \( 3 \equiv 32 \), then

\[ 2 \rightarrow 3 \equiv 23 \]

Hence,

\[ 1 \rightarrow T_1 = \begin{array}{ccc}
1 & 1 & 2 & 3 \\
2 & 3 & \\
3 & 2 & 
\end{array} \]

3.3.5. Example. Consider a symplectic tableau

\[ T_2 = \begin{array}{ccc}
1 & 1 & 2 & 3 \\
2 & 3 & 3 & \\
3 & 3 & 
\end{array} \]
and a letter $x = 3$. Let us compute $x \rightarrow T_2$. First, we begin inserting $x = 3$ in the first column $C_1$ of $T_2$. The word $1233$ is a nonadmissible column, that each strict factor is an admissible column word, we have by applying $(R_3)$,

$$1233 \equiv 12,$$

then

$$\widetilde{C}_1 = \begin{pmatrix} 1 \\ 2 \\ 3 \end{pmatrix} \quad \text{and} \quad \widehat{T}_2 = \begin{pmatrix} 1 & 2 & 3 \\ 3 & 3 & 3 \\ 3 & 3 & 3 \end{pmatrix}.$$ 

So we have to insert the elements of the column $\widetilde{C}_1$ in the tableau $\widehat{T}_2$.

First, one inserts $1$ :

$$1331 \equiv 1313 \equiv 1133,$$

then

$$1 \rightarrow \begin{pmatrix} 1 \\ 3 \\ 3 \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 3 & 3 \\ 3 & 3 \end{pmatrix}.$$ 

We have $231 \equiv 213$, then

$$1 \rightarrow \begin{pmatrix} 2 \\ 3 \\ 3 \end{pmatrix} = \begin{pmatrix} 1 & 2 \\ 3 & 3 \\ 3 & 3 \end{pmatrix}.$$ 

And

$$2 \rightarrow \begin{pmatrix} 3 \\ 3 \end{pmatrix} = \begin{pmatrix} 2 & 3 \\ 3 & 3 \end{pmatrix}.$$ 

Hence

$$1 \rightarrow \widehat{T}_2 = \begin{pmatrix} 1 & 1 & 2 & 3 \\ 3 & 3 & 3 & 3 \\ 3 & 3 & 3 & 3 \end{pmatrix} = \widehat{T}_2'.$$

Secondly, one inserts $2$ in the tableau $\widehat{T}_2'$ :

we have $1332 \equiv 1323 \equiv 3123$, then

$$2 \rightarrow \begin{pmatrix} 1 \\ 3 \\ 3 \end{pmatrix} = \begin{pmatrix} 1 & 3 \\ 3 & 3 \\ 3 & 3 \end{pmatrix}.$$ 

We have $133 \equiv 313$, then

$$3 \rightarrow \begin{pmatrix} 1 \\ 3 \\ 3 \end{pmatrix} = \begin{pmatrix} 1 & 3 \\ 3 & 3 \end{pmatrix}.$$ 

We have $23 \equiv 23$, then

$$3 \rightarrow \begin{pmatrix} 2 \\ 3 \end{pmatrix} = \begin{pmatrix} 2 & 3 \\ 3 & 3 \end{pmatrix}.$$ 

Hence,

$$2 \rightarrow \widehat{T}_2' = \begin{pmatrix} 1 & 1 & 2 & 3 \\ 2 & 3 & 3 & 3 \\ 3 & 3 & 3 & 3 \end{pmatrix} = 3 \rightarrow T_2.$$
3. Plactic monoid for type C

3.3.6. Remark. Consider a word \( w \) on \( C_n^* \). The symplectic tableau \( P(w) \) can be computed by starting with the empty word, which is a valid tableau, and iteratively applying the insertion schemes described above. Notice that when \( w \) is the reading of a symplectic tableau \( T \), \( P(w) = T \).

Let \( u \) and \( v \) be the readings of two admissible columns \( U \) and \( V \) respectively. As we have seen in the subsection 3.3.1, \( U \not\supseteq V \) means that the column \( U \) appears to the right of \( V \) in a symplectic tableau. Note that \( U \not\supseteq V \) means that the word \( uv \) is the reading of a nonsymplectic tableau.

3.3.7. Lemma. Let \( u \) and \( v \) be the readings of two admissible columns \( U \) and \( V \) respectively, such that \( U \not\supseteq V \). The symplectic tableau \( P(uv) \) consists of at most two columns.

Proof. Let \( u = x_1 \cdots x_p \) and \( v = y_1 \cdots y_q \) be respectively the readings of two admissible columns \( U \) and \( V \) of height \( p \) and \( q \), such that \( U \not\supseteq V \). We begin inserting the first element \( y_1 \) of \( v \) in the column \( U \). The shape of \( P(uv_1) \) depends on the connected component containing \( u_1 \). The highest weight vertex of this component can be written \( u^i_1v_1^0 \). By Lemma 2.2.2, \( u^0 \) is of highest weight and \( \varepsilon_i(y_1^0) \leq \varphi_i(u^0) \), for any \( i = 1, \ldots, n \). Then we obtain the following cases:

(a) \( u^i_1v_1^0 = 1 \cdots p(p+1) \). In this case, \( uv_1 \) is an admissible column word and \( \text{wt}(y_1^0) = p + 1 \) = \( \Lambda_p + 1 - \Lambda_p \). Then during the insertion of the letter \( y_1 \) in the column \( U \), this column of height \( p \) corresponding to the weight \( \Lambda_p \) is transformed into a column of height \( p + 1 \) corresponding to the weight \( \Lambda_p + 1 \). Its reading is \( uv_1 \). After one continues inserting the others elements \( y_2, \ldots, y_q \) of the column word \( v \). We know by the definition of an admissible column that every element of this column is strictly larger than its preceding, then we have:

First, suppose that \( y_i^0 = p + i \), for \( i = 2, \ldots, q \). Then \( \text{wt}(y_1^0) = \Lambda_{p+i} - \Lambda_{p+i-1} \) and during the insertion of \( y_i \) in the column of reading \( uv_1 \cdots y_{i-1} \), this column of height \( p + i - 1 \) is turned into the column of reading \( uv_1 \cdots y_i \) and of height \( p + i \). Thus \( u \) is an admissible column word and \( P(uv) \) consists of one column \( uv \).

Secondly, suppose that there exists an element \( y_k \) of the column word \( v \) such that \( uv_1 \cdots y_{k-1}y_k \) is a nonadmissible column word whose each strict factor is an admissible column word, then \( y_k^0 = p + k - 1 \) and \( \text{wt}(y_k^0) = \Lambda_{p+k} - \Lambda_{p+k-1} \), then during the insertion of \( y_k \) in the admissible column of reading \( uv_1 \cdots y_{k-1} \), this column of height \( p + k - 1 \) is transformed into a column of height \( p + k - 2 \). After one continues inserting the remaining elements of \( v \), then one adds those letters in distinct rows in the considered column or one removes some letters from distinct rows of the same column.

Hence, in this case \( P(uv) \) consists of one column.

(b) \( u^i_1v_1^0 = 1 \cdots p \). In this case, \( uv_1 \) is a nonadmissible column word such that each strict factor is an admissible column word. We have \( \text{wt}(y_1^0) = \Lambda_{p+1} - \Lambda_p \), then during the insertion of \( y_1 \) in the admissible column \( U \), this column of height \( p \) is turned into a column of height \( p - 1 \). Since the elements of the column \( V \) are strictly increasing, one can prove by similar arguments of the case (a), that during the computation of \( P(uv_1y_2 \cdots y_q) \), one adds a number of boxes of the considered column in distinct rows and one removes some boxes from distinct rows of the same column. Hence, we have also in this case, that \( P(uv) \) consists of one column.

(c) \( u^i_1v_1^0 = 1 \cdots p \). In this case, \( uv_1 \) is not a column word, then during the insertion of \( y_1 \) in the admissible column \( U \), an element appears in a second column. After, one inserts the next element \( y_2 \)
of the column \( V \) in \( \text{P}(uy_1) \), the highest weight of the connected component containing \( w(\text{P}(uy_1))y_2 \) may be written \( w(\text{P}(uy_1)^p)\lambda_p^2 \), where \( w(\text{P}(uy_1)^p) \) is of highest weight and by Lemma 2.2.2 we have:

(i) \( \lambda_p^2 = i \) (with \( i = p + 1 \) or \( i = 2 \)), then its weight is equal to \( \Lambda_i - \Lambda_{i-1} \), then during the insertion \( y_2 \rightarrow \text{P}(uy_1) \) a column of height \( i - 1 \) is turned into a column of height \( i \). Then one adds a box in the first column or in the second column of \( \text{P}(uy_1) \).

(ii) \( \lambda_p^2 = p \), then its weight is equal to \( \Lambda_{p-1} - \Lambda_p \), then during the insertion \( y_2 \rightarrow \text{P}(uy_1) \), the first column of height \( p \) is turned into a column of height \( p - 1 \).

After we continue inserting the remaining letters of \( v \), and since every element is strictly larger than its preceding, one adds boxes in distinct rows in the first or in the second column and similarly one removes boxes from distinct rows of the considered symplectic tableau. Hence, \( \text{P}(uv) \) consists of two columns.

\[ \square \]

3.3.8. Lemma. Let \( u \) and \( v \) be the readings of two admissible columns \( U \) and \( V \) respectively, such that \( U \nless V \). Then the column \( U \) contains more elements than \( W \), the right column of \( \text{P}(uv) \).

Proof. Let \( u = x_1 \cdots x_p \) and \( v = y_1 \cdots y_q \) be respectively the readings of two admissible columns \( U \) and \( V \) of height \( p \) and \( q \), such that \( U \nless V \). Let \( w \) and \( w' \) be respectively the readings of the right and left column \( W \) and \( W' \) of \( \text{P}(uv) \). If the height of \( U \) is greater than the height of \( V \), then in all cases we have \( h(W) < p \). Suppose now that \( q \geq p \) and the columns \( U \) and \( V \) contain only unbarred letters. Suppose that during the computation of \( \text{P}(uv) \), we only add boxes by applying relations of type \( (R_1) \). If \( h(W) = p \), then during inserting the first \( p \) elements of \( V \), \( p \) boxes are added in the second column and they are all filled by elements of \( U \). Since the number of added boxes is equal to the height of \( U \), \( w(\text{P}(uv)) = uv \). Then \( U \nless V \) which yields a contradiction. Hence, \( h(W) < p \).

Suppose now that during the computation of \( \text{P}(uv) \), we only add boxes by applying relations of type \( (R_1) \) or \( (R_2) \). By the definition of \( \text{P}(uv) \) we have \( w(\text{P}(uv)) = vv' \equiv uv \). Then the words \( uv \) and \( vv' \) occur at the same place in their isomorphic connected components \( B(uv) \) and \( B(vv') \) of the crystal \( G_n \). Note that all the vertices in a connected component are the readings of tableaux of same shape. Let \( (uv)^0 \) and \( (vv')^0 \) be respectively the highest weight vertices of \( B(uv) \) and \( B(vv') \). The word \( (vv')^0 \) is the reading of a tableau that all its elements are unbarred letters, then \( (uv)^0 \) and \( (vv')^0 \) are related by relations of type \( (R_1) \). Hence, as we have seen above, the height of the second column of \( \text{P}(uv)^0 \) is strictly less than \( p \). Since \( (vv')^0 \) and \( vv' \) are the readings of two symplectic tableaux of same shape, the length of \( w \) is strictly less than \( p \).

Suppose that during the insertion of the first \( k \) elements of \( v \), for \( k \leq p - 1 \), into the column \( U \), we add \( k \) boxes in a second column. Then

\[ \text{P}(uy_1 \cdots y_k) = \begin{array}{c|c} C_1 & \end{array} \]

where \( C_1 \) contains \( p \) elements and \( C_2 \) contains the \( k \) added boxes. After we insert \( y_{k+1} \) in the column \( C_1 \). Suppose that \( w(C_1)y_{k+1} \) is a nonadmissible column word such that all of its proper factors are admissible. Let \( w(C_1)y_{k+1} \) be the column word obtained from \( w(C_1)y_{k+1} \) after applying relation of
4. Convergent presentation of plactic monoid for type C

We consider a presentation of the symplectic plactic monoid $\text{Pl}(C)$, by the 2-polygraph $\Sigma^{\text{Sp}(n)}$, whose set of 1-cells is $C_n$ and whose 2-cells correspond to the relations $(R_1)$, $(R_2)$ and $(R_3)$ oriented with respect to the reverse deglex order, that is

$$\Sigma^{\text{Sp}(n)}_2 = \{ \text{xzy} \xrightarrow{K_{x,y,z}} \text{zyx} \mid x < y \leq z \text{ and } z \neq \overline{x} \}$$

$$\cup \{ \text{yxz} \xrightarrow{K'_{x,y,z}} \text{yzx} \mid x \leq y < z \text{ and } z \neq \overline{x} \}$$

$$\cup \{ \text{yxz} \xrightarrow{\tilde{K}_{x,y,z}} \text{xyz} \mid x \leq y \leq z \text{ and } 1 < x \leq n \}$$

$$\cup \{ \text{yw} \xrightarrow{\tilde{\xi}_{x,y,z}} \text{w} \mid \text{w and } \tilde{\text{w}} \text{ satisfy the conditions of the relation } (R_3) \}.$$ 

The order being monomial, the 2-polygraph $\Sigma^{\text{Sp}(n)}$ is terminating.

4.0.9. Theorem. For $n \geq 4$, there is no finite completion of the 2-polygraph $\Sigma^{\text{Sp}(n)}$ compatible with the reverse deglex order.

Proof. We know that for $n = 4$, the Knuth presentation of the plactic monoid for type A doesn’t admit a finite completion compatible with the reverse deglex order because during the completion one adds an infinity of 2-cells of the form $232^i124 \xrightarrow{2342^i12}$, for $i > 1$. Since the 2-polygraph $\Sigma^{\text{Sp}(n)}$ contains the Knuth relations for type A, it doesn’t also admit a finite completion compatible with the reverse deglex order.

In order to give a finite convergent presentation of the symplectic plactic monoid $\text{Pl}(C)$, one introduces the admissible column generators. The set of generators is

$$\Gamma_1 = \{ c_u \mid u \text{ is an admissible column word of } C_n^* \},$$

where each symbol $c_u$ represents the element $u$ of $\text{Pl}(C)$. We know that $C_n$ consists of columns of one element, then the set $\Gamma_1$ also generates $\text{Pl}(C)$.

We consider the two following sets of 2-cells, the 2-cells corresponding to the relations $(R_1)$, $(R_2)$
4. Convergent presentation of plactic monoid for type C

and \( (R_3) \), that is,

\[
\Gamma_{2}^{\text{Sp}(n)} = \left\{ c_{x}c_{y}c_{z} \xrightarrow{c_{y}c_{z}} c_{z}c_{y} \mid x < y \leq z \text{ and } z \neq \bar{x} \right\}
\]

\[
\bigcup \left\{ c_{y}c_{z}c_{x} \xrightarrow{c_{z}c_{x}} c_{y}c_{z}c_{x} \mid x \leq y < z \text{ and } z \neq \bar{x} \right\}
\]

\[
\bigcup \left\{ c_{y}c_{x}c_{\bar{x}} \xrightarrow{c_{x}c_{\bar{x}}} c_{y}c_{x}[x-1]c_{[x-1]} \mid x \leq y \leq \bar{x} \text{ and } 1 < x \leq n \right\}
\]

\[
\bigcup \left\{ c_{x}c_{\bar{x}}c_{y} \xrightarrow{c_{\bar{x}}c_{y}} c_{x}c_{[x-1]}c_{[x-1]}c_{y} \mid x \leq y \leq \bar{x} \text{ and } 1 < x \leq n \right\}
\]

\[
\bigcup \left\{ c_{x_{1}} \cdots c_{x_{w_{1}}} \xrightarrow{c_{x_{1}}} c_{x_{1}} \cdots c_{x_{w_{1}}} \mid \text{w and } \tilde{w} \text{ verify the conditions of the relation } (R_3) \right\}
\]

where \( w = x_{1} \cdots x_{|w|} \) and \( \tilde{w} = \tilde{x}_{1} \cdots \tilde{x}_{|w|} \), and the 2-cells corresponding to the defining relations for the extra column generators \( c_{u_{i}} \), where \(|u_{i}| \geq 2\).

\[
\Gamma_{2}^{\text{c}(n)} = \left\{ c_{y_{1}} \cdots c_{y_{k}} \xrightarrow{\gamma_{y_{1} \cdots y_{k}}} c_{y_{1} \cdots y_{k}} \mid y_{1} \cdots y_{k} \text{ is an admissible column word of } C_{n}^{*} \right\}
\]

The monoid \( \text{Pl}(C) \) is presented by the 2-polygraph \( \Gamma^{(n)} = (\Gamma_{1}, \Gamma_{2}^{(n)}) \), with \( \Gamma_{2}^{(n)} = \Gamma_{2}^{\text{Sp}(n)} \cup \Gamma_{2}^{\text{c}(n)} \).

Let \( u \) and \( v \) be respectively the readings of two admissible columns \( U \) and \( V \). Suppose that \( U \nRightarrow V \), let us define a 2-cell

\[
c_{u}c_{v} \xrightarrow{\alpha_{u\gamma}} c_{w}c_{w'}
\]

where the words \( w \) and \( w' \) are respectively the readings of the right and left columns \( W \) and \( W' \) of \( P(uv) \) if this symplectic tableau consists of two columns. Moreover, if \( P(uv) \) consists of one column \( W \), then \( w' \) is the empty word.

Define

\[
\Omega_{2} = \left\{ c_{u}c_{v} \xrightarrow{\alpha_{u\gamma}} c_{w}c_{w'} \mid u \text{ and } v \text{ are admissible column words of } C_{n}^{*} \text{ and } U \nRightarrow V \right\}
\]

The 2-polygraph \( \Sigma_{\text{col}(n)} = (\Gamma_{1}, \Omega_{2}) \) is called the \textit{admissible column presentation}.

Let us define an order on \( \Gamma_{1}^{*} \). First, choose an order \( \sqsubseteq \) on \( \Gamma_{1} \) such that \( c_{u} \sqsubseteq c_{v} \) if \( |u| < |v| \). Secondly, consider the order \( \prec \) on \( \Gamma_{1}^{*} \), defined as follows. We have

\[
c_{u_{1}}c_{u_{2}} \cdots c_{u_{m}} \prec c_{v_{1}}c_{v_{2}} \cdots c_{v_{n}}
\]

if \( |(m < n)| \) or \( (m = n \text{ and there exists } i \text{ such that } : c_{u_{i}} \sqsubseteq c_{v_{i}} \text{ and } \forall j < i, c_{u_{j}} = c_{v_{j}}) \]

where \( c_{u_{i}} \) and \( c_{v_{j}} \) are elements of \( \Gamma_{1} \), for \( i = 1, \cdots, m \) and \( j = 1, \cdots, n \). Thus \( \prec \) is a well-ordering on \( \Gamma_{1}^{*} \).

\textbf{4.0.10. Lemma.} \textit{The 2-polygraph } \( \Sigma_{\text{col}(n)} \) \textit{is finite.}

\textit{Proof.} The symplectic tableau \( P(u) \) is unique for each word \( u \), then for two admissible columns words \( u \) and \( v \) of \( C_{n}^{*} \), the 2-cells of the form \( \alpha_{u\gamma} \) are uniquely determined. In addition, \( \Gamma_{1} \) is finite thanks to the fact that the admissible columns words of \( C_{n}^{*} \) have length at most \( n \). \hfill \Box
4. Convergent presentation of plactic monoid for type C

The following lemma shows that the plactic monoid \( \Pi(C) \) is presented by the 2-polygraph \( \Sigma^{acol(n)} \):

**4.0.11. Lemma.** The 2-polygraphs \( \Gamma^{(n)} \) and \( \Sigma^{acol(n)} \) are tietze equivalent.

*Proof.* Every relation in \( \Omega_2^{Sp(n)} \) can be deduced from rules in \( \Omega_2 \), indeed,

\[
\begin{align*}
\alpha_{x,y} & \iff \alpha_{x,y} \circ \alpha_{y,z} \iff \alpha_{x,z}, \\
\alpha_{x,y} & \iff \alpha_{x,y} \circ \alpha_{y,x} \iff \alpha_{y,x}.
\end{align*}
\]

Let \( w = x_1 \cdots x_p \cdots x_q \cdots x_k \) be a nonadmissible column word of length \( k \) such that each strict factor of \( w \) is an admissible column word. Let \( z = x_p \) be the lowest unbarred letter such that the pair \( (z = x_p, \overline{z} = x_q) \) occurs in \( w \) and \( N(z) = z + 1 \). Then we have:

\[
\begin{align*}
\alpha_1 & = \alpha_{x_1 \cdots x_{q-1}, x_q, x_{q+1} \cdots x_k} \circ \alpha_{x_{q-1}, x_q, x_{q+1} \cdots x_k} \circ \alpha_{x_{q-1}, x_q, x_{q+1} \cdots x_k}, \\
\alpha_2 & = \alpha_{x_1 \cdots x_{p-1}, x_p, x_{q-1} \cdots x_k} \circ \alpha_{x_1 \cdots x_{p-1}, x_p, x_{q-1} \cdots x_k}, \\
\alpha_3 & = \alpha_{x_1 \cdots x_{p-1}, x_p, x_{q-1} \cdots x_k} \circ \alpha_{x_1 \cdots x_{p-1}, x_p, x_{q-1} \cdots x_k}.
\end{align*}
\]

where the symbol \( \hat{x} \) means that \( x \) is removed, \( \alpha_1 = \alpha_{x_1 \cdots x_{q-1}, x_q, x_{q+1} \cdots x_k} \circ \alpha_{x_{q-1}, x_q, x_{q+1} \cdots x_k} \circ \alpha_{x_{q-1}, x_q, x_{q+1} \cdots x_k} \)
and \( \alpha_3 = \alpha_{x_1 \cdots x_{p-1}, x_p, x_{q-1} \cdots x_k} \circ \alpha_{x_1 \cdots x_{p-1}, x_p, x_{q-1} \cdots x_k} \).

In addition, any rules in \( \Gamma^{(n)}_2 \) can be obtained using those in \( \Omega_2 \):

\[
\begin{align*}
\alpha_{u_1 \cdots u_k} & \iff \alpha_{u_1 \cdots u_k} \circ \alpha_{u_{k-1}, u_k}, \\
\alpha_{u_1 \cdots u_k} & \iff \alpha_{u_1 \cdots u_k} \circ \alpha_{u_{k-1}, u_k}, \\
\alpha_{u_1 \cdots u_k} & \iff \alpha_{u_1 \cdots u_k} \circ \alpha_{u_{k-1}, u_k}.
\end{align*}
\]
4. Convergent presentation of plactic monoid for type C

4.0.12. **Remark.** Every rule in $\Omega_2$ holds in the symplectic plactic monoid $\mathbf{Pl}(C)$, indeed,

$$c_u c_v \equiv uv \equiv w(P(uv)) = ww' \equiv c_w c_{w'}.$$

4.0.13. **Theorem.** The 2-polygraph $\Sigma^{\text{acol}(n)}$ is a finite convergent presentation of the symplectic plactic monoid $\mathbf{Pl}(C)$.

**Proof.** By Lemma 4.0.10, the 2-polygraph $\Sigma^{\text{acol}(n)}$ is finite. Let us show that it also convergent. First, the 2-polygraph $\Sigma^{\text{acol}(n)}$ is terminating. Indeed, we have to prove that if $h \Rightarrow h'$, then $h' \prec h$. One finds two cases:

- First case: let $h = pc_u c_v q$ and $h' = pc_w c_{w'} q$, with $p, q \in \Gamma^+_1$ and $c_u, c_v, c_w \in \Gamma_1$. One remarks that $h'$ is shorter than $h$, then $h' \prec h$.

- Second case: let $h = pc_u c_v q$ and $h' = pc_w c_{w'} q$, with $p, q \in \Gamma^+_1$ and $c_u, c_v, c_w, c_{w'} \in \Gamma_1$, where $w$ and $w'$ are respectively the readings of the right and left columns of $P(uv)$. One remarks that $h$ and $h'$ have the same length. By Lemma 3.3.8, the length of $u$ is strictly larger than the length of $w$, then $c_w \sqsubseteq c_u$. If we consider $i = |p| + 1$, then we have $c_{ui} = c_w \sqsubseteq c_{ui} = c_w$ and for all $j < i$, $c_{ui} = c_{vi}$. Then, $h' \prec h$. Since every application of a 2-cell of $\Omega_2$ yields a $\prec$-preceeding 1-cell, it follows that any sequence of rewriting using $\Omega_2$ must terminate. Hence, the 2-polygraph $\Sigma^{\text{acol}(n)}$ is terminating.

Secondly, the 2-polygraph $\Sigma^{\text{acol}(n)}$ is confluent. Indeed, let $h \in \Gamma^+_1$ and $h', h''$ be two normal forms obtained from $h$. Since $\Sigma^{\text{acol}(n)}$ is terminating, $h'$ and $h''$ exist. We have to prove that $h = h'$. Suppose that $h' = c_{ui} \cdots c_{uj}$. Since $h'$ is a normal form, the words $u_1, \ldots, u_k$ are respectively the readings of $k$ admissible columns $U_1, \ldots, U_k$ of a symplectic tableau, i.e., $U_i \leq U_{i+1}, \forall i$. Then $u_k \cdots u_1 = w(T')$, where $T'$ is the unique symplectic tableau such that

$$w(T') = u_k \cdots u_1 \equiv h'.$$

Similarly, $h'' = c_{v_1} \cdots c_{v_l}$ is a normal form, then there exists a unique symplectic tableau $T''$ such that

$$w(T'') = v_l \cdots v_1 \equiv h''.$$ 

Since $h \equiv h' \equiv h''$, we have by Theorem 3.2.3 that $T' = T''$. Then we have $k = l$ and $u_i = v_i, \forall i = 1, \ldots, k$. Thus $h' = h''$.

Hence, the 2-polygraph $\Sigma^{\text{acol}(n)}$ is convergent. $\square$

Since plactic monoids for type C admit finite convergent presentations, we obtain by Corollary 4.5.4 in [GM12] that they satisfy the homotopical finiteness condition $\text{FDT}_\infty$. This result yields by Corollary 5.4.4 in [GM12] that plactic monoids for type C satisfy the homological finiteness property type $\text{FP}_\infty$. 

17
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