

1 Rigidity Conjecture

Remark. When studying compositions of formal power series, we require that the inner power series $f(X)$ has no constant term, i.e., $f(0) = 0$. This condition ensures that the resulting composition is well-defined in the ring of formal power series $\mathbb{C}[[X]]$, as it prevents infinite contributions to the coefficients.

Consider $f(X) = \sum_{k \geq 1} a_k X^k$ and $g(X) = \sum_{k \geq 0} b_k X^k$. The composition $g(f(X))$ is given by substituting $f(X)$ into $g(X)$:

$$\begin{aligned} g(f(X)) &= b_0 + b_1 f(X) + b_2 f(X)^2 + \dots \\ &= b_0 + b_1(a_1 X + a_2 X^2 + \dots) + b_2(a_1 X + a_2 X^2 + \dots)^2 + \dots \\ &= b_0 + b_1 a_1 X + (b_1 a_2 + b_2 a_1^2) X^2 + \dots, \end{aligned}$$

where we grouped the terms by powers of X in the last step. We observe that the coefficients of X^n in $g(f(X))$ depend only on a finite number of coefficients of $f(X)$ and $g(X)$. This is because, with $f(0) = 0$, each power $f(X)^k$ introduces terms of degree at least k , ensuring that lower-degree terms do not contribute infinitely to higher-order coefficients.

On the other hand, if $f(0) \neq 0$, we write $f(X) = a_0 + \sum_{k \geq 1} a_k X^k$, where $a_0 = f(0)$. In this case,

$$f(X)^k = (a_0 + a_1 X + a_2 X^2 + \dots)^k$$

produces a constant term $a_0^k \neq 0$. Consequently, the constant term of $g(f(X))$ depends on infinitely many terms of $g(X)$, and the composition $g(f(X))$ is no longer a formal power series.

Since we are interested in the compositional inverse, it is necessary to extend the condition $f(0) = 0$ to both power series. This ensures that the inverse series $f^{-1}(X)$, when substituted into $f(X)$, results in the identity series X , with no contributions from constant terms that would otherwise make the series ill-defined.

The following proposition and lemma are taken from Enumerative Combinatorics by Richard P. Stanley and Sergey Fomin.

Definition 1. Let $f(X) \in \mathbb{C}[[X]]$ be a power series with no constant term. We call a power series $f^{-1}(X) \in \mathbb{C}[[X]]$ the compositional inverse of f , if it satisfies $f(f^{-1}(X)) = f^{-1}(f(X)) = X$.

Proposition 2. A power series $f(X) = a_1 X + a_2 X^2 + \dots \in \mathbb{C}[[X]]$ has a compositional inverse if and only if $a_1 \neq 0$. Moreover, if the compositional inverse exists, then it is unique.

Proof. Assume f has a compositional inverse and denote the compositional inverse by $f^{-1}(X) = b_1 X + b_2 X^2 + \dots$. Writing out $f(f^{-1}(X)) = X$ using multinomial theorem gives

$$\begin{aligned} X &= a_1(b_1 X + b_2 X^2 + \dots) + a_2(b_1 X + b_2 X^2 + \dots)^2 + \dots \\ &= (a_1 b_1 X + a_1 b_2 X^2 + a_1 b_3 X^3 + \dots) + (a_2 b_1^2 X^2 + 2a_2 b_1 b_2 X^3 + \dots) \\ &= (a_1 b_1) X + (a_1 b_2 + a_2 b_1^2) X^2 + (a_1 b_3 + 2a_2 b_1 b_2 + a_3 b_1^3) X^3 \dots \end{aligned}$$

Equating the coefficients on both sides yields a linear system of equations.

$$\begin{aligned} 1 &= a_1 b_1 \\ 0 &= a_1 b_2 + a_2 b_1^2 \\ 0 &= a_1 b_3 + 2a_2 b_1 b_2 + a_3 b_1^3 \\ &\vdots \end{aligned}$$

The first equation has a solution if and only if $a_1 \neq 0$. In that case, the solution is unique. Then, the second equation can be solved uniquely for b_2 . By this process, we are able to solve the third equation for b_3 , the fourth for b_4 and so on. Thus, $f^{-1}(X)$ exists if and only if $a_1 \neq 0$ and in that case, $f^{-1}(X)$ is unique. \square

Lemma 3 (Lagrange Inversion Formula). Let $f(X) = \sum_{k \geq 1} a_k X^k \in \mathbb{C}[[X]]$ be a power series with $a_1 \neq 0$ and denote its composition inverse by $f^{-1}(X) = \sum_{k \geq 1} b_k X^k \in \mathbb{C}[[X]]$. The coefficients of the inverse is given by the following formula.

$$b_k = \frac{1}{k} [X^{n-1}] \left(\frac{X}{f(X)} \right)^k$$

Proof. We begin by substituting $f(X)$ into $f^{-1}(X)$. It is

$$X = f^{-1}(f(X)) = \sum_{k \geq 1} b_k f(X)^k.$$

Differentiating and subsequently taking the quotient with $f(X)^n$ for $n \in \mathbb{N}$ on both sides yields

$$\begin{aligned} 1 &= \sum_{k \geq 1} k \cdot b_k \cdot f(X)^{k-1} \cdot f'(X) \\ \Rightarrow \quad \frac{1}{f(X)^n} &= \sum_{k \geq 1} k \cdot b_k \cdot \frac{f(X)^k}{f(X)^{n+1}} \cdot f'(X). \end{aligned}$$

We want to take the coefficient of X^{-1} on both sides. For that, first notice that for $k \neq n$ it is

$$\frac{1}{k-n} \frac{d}{dX} f(X)^{k-n} = f(X)^{k-n-1} f'(X) = \frac{f(X)^k}{f(X)^{n+1}} f'(X).$$

For any Laurent series, its derivative has no X^{-1} term. Thus, for $k \neq n$, it is

$$[X^{-1}] \frac{f(X)^k}{f(X)^{n+1}} f'(X) = [X^{-1}] \frac{1}{k-n} \frac{d}{dX} f(X)^{k-n} = 0.$$

If we now take the coefficient of X^{-1} in #REFMISSING, we get

$$[X^{-1}] \frac{1}{f(X)^n} = [X^{-1}] \sum_{k \geq 1} k \cdot b_k \cdot \frac{f(X)^k}{f(X)^{n+1}} \cdot f'(X) \tag{1}$$

$$= \sum_{k \geq 1} k \cdot b_k \cdot [X^{-1}] \frac{f(X)^k}{f(X)^{n+1}} \cdot f'(X) \tag{2}$$

$$= n \cdot b_n [X^{-1}] \frac{f(X)^n}{f(X)^{n+1}} \cdot f'(X) \tag{3}$$

$$= n \cdot b_n [X^{-1}] \frac{f'(X)}{f(X)} \tag{4}$$

$$= n \cdot b_n [X^{-1}] \frac{a_1 + 2a_2X + 3a_3X^2 + \dots}{a_1X + a_2X^2 + a_3X^3 + \dots} \tag{5}$$

Since we are only interested in the coefficient of X^{-1} , in the last expression, we have $a_1 a_1^{-1} X^{-1} = X^{-1}$, hence

$$[X^{-1}] \tag{6}$$

□