JIS Journal of Interdisciplinary Sciences
Volume 7, Issue 1; 29-54
May, 2023. © The Author(s)
ISSN: 2594-3405

Self-move and Other-move: Quantum Categorical Foundations of Japanese

Ryder Dale Walton
Capitol Technical University, USA
rdwalton@captechu.edu

Abstract: *This work contributes toward the larger goal of creating a Quantum Natural Language Processing (QNLP) translation program. It contributes original diagrammatic representations of the Japanese language based on previous work on the English language. The germane differences between the English and Japanese languages are emphasized to help address English language bias in the current body of research. Additionally, topological principles of these diagrams and many potential avenues for further research are proposed. This endeavor is crucial because languages are foundational to human survival, experience, flourishing, and living the good life. They are also, however, among the strongest barriers between people groups. Over the last several decades, advancements in Natural Language Processing (NLP) have somewhat bridged the gap between individuals without a common language or culture. While tools like Chat-GPT, Google Translate, and DeepL make it easier than ever before to share our experiences with people globally, these tools are nevertheless inadequate as they fail to convey our ideas across the language barrier fluently, leaving people feeling anxious and embarrassed, because they cannot understand grammar or context. Quantum computers offer the best chance to achieve translation fluency in that they are better suited to simulating the natural world and natural phenomena such as speech.*

Keywords: Japanese grammar; QNLP; category theory; DisCoCat, DisCoCirc; translation; topology

Introduction

Natural Language Processing (NLP) is a field of great interest which continues to produce significant new technologies. Indeed, the ongoing success of NLP cannot be oversold. Artificial Intelligences, like Chat-GPT, voice assistants, like Siri and Google Assistant, and smart home hubs, like Amazon Alexa, Google Home, and Apple HomePod, rely on NLP for commands and basic functions. This includes reception of audio, generating text, parsing it into tokens, processing the tokens, finding search results, and more. If classical computers provide all these NLP benefits and successes, why spend the time to research what quantum computers can do?

The Problem

NLP, despite its resounding success and significant forward momentum, continues to fail to produce fluent translations. Consider Google Translate or DeepL. These applications translate well enough that people across cultures can communicate with one another. That alone is a modern marvel, but if one asks whether machine translations sound natural—sound fluent—at all, then the reply would likely be "No". This is because machine translators know nothing about culture, context, and grammar. Thus, they know nothing about language. They know much about corpora, probability, and "bags of words" though, which is enough to effectively translate single sentences (Coecke et al., 2020). However, for all its continued and future success, it absolutely cannot translate sentences with a knowledge of grammar and context. Fluency eludes its grasp. It is, therefore, still necessary to rely on humans in most situations where trans-cultural communication is required. Machines are insufficient for corporate meetings, travel tours, lengthy interpersonal interactions, and in humanitarian emergencies. This study takes one step toward solving this problem by extending and illuminating English grammar research in the field of *Quantum Natural Language Processing* (QNLP) to Japanese grammar.

Because language is a natural phenomenon, like molecular systems, QNLP is a promising solution to the problem of fluency. In fact, the underlying mathematics of both reduces to the same category theoretic representation—compact closed categories (Zeng & Coecke, 2016). The main problem associated with modeling languages and molecules is resource limitations on classical computers. This, then, is precisely why quantum computers fit the bill. Modeling processes require many, many variables and have many, many possible outcomes. Such problems are considered "quantum-native" because quantum computers provide the needed resources that classical computers lack (QNLP, 2019). Namely, the tensor product of many qubits provides an exponential space advantage over classical bits (Meichanetzidis et al., 2021). Suddenly, with quantum grammar and semantics modeling, machine-generated translation fluency enters the realm of possibility (Zeng & Coecke, 2016). Quantum Computers, then, can translate sentences with knowledge of grammar and context.

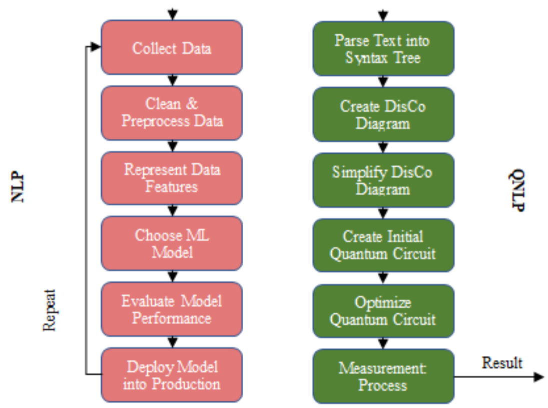

Figure 1 NLP Vs. QNLP Implementation
Note. This image is derived from multiple sources (Chen, 2020; Lorenz et al., 2021; Meichanetzidis et al., 2021).

The NLP implementation relies entirely on *Machine Learning* (ML), it requires considerable trial and error during each step. Data representations, preprocessing techniques, ML models, evaluation methods, etc., impact the implementation's performance. Additionally, as new information is made available, the model must be retrained. The QNLP approach, on the other hand, leverages grammar and syntax, greatly reducing the number of choices. While creating a quantum circuit from a DisCoCat diagram relies on ansatz and optimization, having a set grammar eliminates the need for retraining over corpora of words.

The purpose of this study is to provide a necessary step toward translating English into Japanese with a high degree of *accuracy*—whether the intended meaning conveyed correctly—and *fluency*—whether the meaning conveyed naturally—by extensively examining self-move, or transitive, and other-move, or intransitive, grammar in Japanese. This study differs from prior research because it begins to uncover blind spots in the literature that exist due to English language bias (Abbaszade et al., 2021). To achieve this, diagrammatic reasoning is used to extend the Japanese pregroup grammar of Cardinal, novel DisCo diagrams are contributed to the field, and novel topological principles of said diagrams are introduced for further research.

Category Theory

All *categories* are made up of two types of entities, "*objects* and *morphisms*" (van de Wetering, 2020). Objects are the subjects of the category theory and morphisms are the legal operations on said subjects. The most basic category is sets. In sets, objects are the sets themselves, and the morphisms are functions that map one set to another.

Categories require two operations. First, categories must have *sequential composition* that is associative in nature. Suppose these morphisms exist in a category: $f: A \to B$ and $g: B \to C$. In relation to sets, these represent a transformation from the set on the left-side of the arrow to the set on the right-side. Sequential composition is nesting two morphisms to create a new one. This produces the following result: $g \circ f: A \to C$, read as "g after f" (Coecke & Kissinger, 2017). Associativity of sequential compositions means that the following is also true: $h \circ (g \circ f) = (h \circ g) \circ f$. In other words, calculating the morphemes in either order produces the same result. Secondly, categories require an *identity* morphism. It is quite simple: $id_A : A \to A$. Simply put, the identity morphism maps the object onto itself. When the identity morphism composes sequentially, the result is as follows: $id_A \circ f = f$.

The complexity of languages and quantum mechanics supersedes that of sets, so they necessitate additional rules. The first missing piece is a representation of simultaneity. Fortunately, *monoidal* categories accomplish this via the tensor product—a special operator denoting the addition of subsystems to represent the sum of objects: $A \otimes B := A + B$ (van de Wetering, 2020). This provides *parallel composition* because it simply asserts that within an object both A and B exist. Parallel composition is not necessarily associative in a monoidal category; however, *symmetric* monoidal categories are associative (van de Wetering, 2020).

A category is called symmetric when $A \otimes B$ and $B \otimes A$ are necessarily isomorphic. In this case, ordering is irrelevant.

The second missing piece is perhaps less intuitive. For a category theory to sufficiently represent quantum mechanics, fluidity of inputs and outputs is necessary. When this capability is present in a symmetric category, it is called *compact closed* (van de Wetering, 2020). This is necessitated by the need to address non-separability. Essentially, there must be some graphical component that signifies entanglement because quantum theory states that some things cannot be divided or separated. It turns out that allowing inputs to connect to inputs and outputs to outputs resolves this (Coecke & Kissinger, 2017). Therefore, a compact closed symmetric monoidal category suffices for this study. It is "the fundamental structure in categorical quantum mechanics" (van de Wetering, 2020).

Compact closed categories also underlie algebraic linguistics (Coecke, 2020). This affirms the assertion that language is quantum native. Words correspond to quantum states, and grammatical structures to quantum measurements (Coecke et al., 2021). Given this revelation, one can solve quantum problems and linguistic problems from the same perspective using the same tools. In fact, using these tools makes the preprocessing of data into a quantum-friendly structure easy (O'Riordan et al., 2020).

Namely, these tools are *string diagrams*—diagrammatic representations of morphisms in compact closed categories. *Cat*egorical *Co*mpositional *Dis*tributional (*DisCoCat*) and *Cir*cuit-shaped *C*ompositional *Dis*tributional (*DisCoCirc*) are two diagrammatic tools for representing category theory-based concepts (Coecke, 2020). Both tools are referred to simultaneously as Compositional Distributional (*DisCo*) diagrams. The idea of distributional structure is beyond the current scope; however, it is worth definition. Simply put, the idea is that grammar enforces order, restrictions, and occurrences of elements in text and speech (Harris, 1954). DisCoCat discerns the semantics of a single sentence and its grammatical correctness, and DisCoCirc operates on a body of text. Each sentence is a process that accepts nouns as inputs, updates their meanings, and outputs them (Coecke, 2020).

String diagrams require "*cups*" and "*caps*", which are named for their appearance (Coecke & Kissinger, 2017). Figure 2 depicts a cup, and Figure 3 depicts a cap. The X represents the original object, which is also referred to as the *base-type*. The X.R and the X.L represent the right and left-adjoint of the base-type. The underlying structure is a selected mathematical grammar, like Lambek's pregroup grammar (Coecke, 2020; Lambek, 1997, 2008). The selection is not critical for later processing (Bolt et al., 2016).

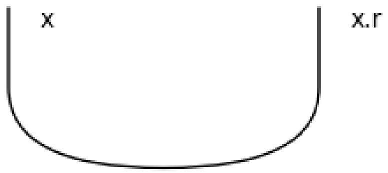

Figure 2 Cup

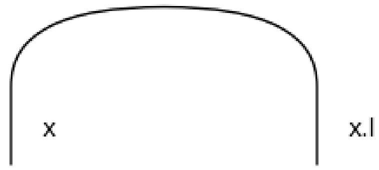

Figure 3 *Cap*

Figure 4 depicts cups and caps in context. This toy diagram is based on an often-used example by Coecke et al., (2020). It is a complete linguistic diagram of a simple *subject-verb-object* (SVO) sentence in English.

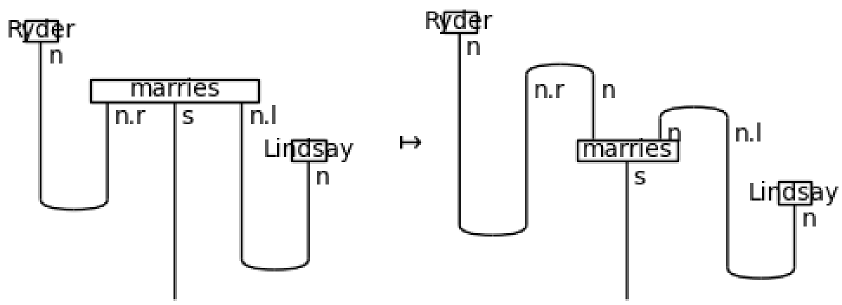

Figure 4 Contextualized Cups and Caps

The left-side is simplified, requiring only cups. Boxes—also often called processes where objects are envisioned as inputs and outputs of a morpheme— represent nouns at the semantic level, while the noun is assigned the pregroup grammar base-type *n* (Coecke & Kissinger, 2017). Transitive verbs appear as boxes with complex wiring. The transitive verb requires two noun connections, one from the left and another from the right. The right-side noun is the object of the verb, while the left-side noun is the subject. The verb, then, contains the right-adjoint and left-adjoint of the subject noun and object noun base-types, respectively. It also outputs some base-type to indicate the correctness of the sentence. This type is *s*. All connections are outputs because they connect to the bottom of the boxes. The subject matrix and its right-adjoint reduce since matrices are necessarily unitary in quantum computation (Coecke et al., 2018). Then, the object matrix and its left-adjoint reduce. Only the sentence type remains. This outcome is understood as proof that the sentence is well-formed.

The right-side depicts an un-simplified diagram. The presence of caps makes this obvious. Ultimately, this is the reason for cups and caps. They provide elegant simplifications called "yanking equations" (Coecke & Kissinger, 2017; Al-Mehairi et al., 2017). By leveraging yanking equations diagrammatic simplifications become straightforward. This work's original diagrams are already simplified.

English QNLP Diagrams

In English, meaning is bound to word order. English follows an SVO word order. Figure 5 is the archetypal example. English word order is enforced by the choice of grammar. The semantic structure of the sentence is built atop said grammar (Bolt et al., 2016). Lambek's pregroup grammar is a popular choice (Lambek, 1997, 2008).

Figure 5 SVO Archetypal Example
Note. This figure is featured in many of Coecke's works (2016, 2020; Coecke et al., 2020, 2021). Whenever words are included in a diagram, it functions at the semantic level.

DisCoCirc processes larger bodies of text. See Figure 6 for an example of an SVO sentence (Coecke, 2020). There are two nouns: Alice and Bob. In a longer text, the meanings of words, particularly nouns, develop (Coecke, 2020). In this case, Alice's meaning is updated. It turns out she is a dog. Bob's meaning is also updated, but he is a person. DisCoCirc also strictly follows SVO. Therefore, Alice is the one who bites Bob.

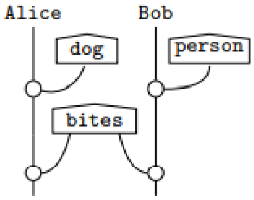

Figure 6 SVO in DisCoCirc
Note. This image originally comes from Coecke's 2020 work.

To be clear, it is not the nouns' positions that determine subject and object. It is the nouns' underwires. Compare the wire orders in Figure 7, with those of Figure 6. The nouns, their wires, and their modifiers have been completely swapped; however, the meaning is the same because the wires connect in the same respective outputs.

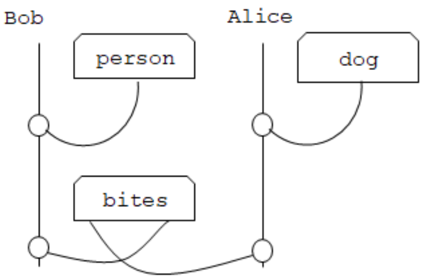

Figure 7 Alice and Bob Swapped

Japanese Compared to QNLP Literature

The word order of Japanese is remarkably fluid. Many contend that Japanese follows a *Subject-Object-Verb* (SOV) word order, but this is not entirely true (Miyagawa, 1999). More importantly, it is not necessary because the *parts of speech* (PoS) are explicitly marked with words called *particles*. Particles mark subjects, objects, directions, add emotion and emphasis, solicit responses and much more. Despite the presence of particles, it is incorrect to assume that word order is totally irrelevant. There are two rules. First, it is mandatory that a sentence ends with a verb, adjective, or the copula. Second, words modify other words that follow them (Miyagawa, 1999). Typically, modification is limited to directly adjacent words, but adverbs have greater flexibility. Depending on the use of particles, Japanese sentences take different forms. The first of these can is *self-move* (自動詞[jidoushi]) or transitive, while the second is *other-move* (他動詞[tadoushi]) or intransitive (Dolly, 2018b).

Self-move sentences are often simple. The kernel of the sentence is a subject, the particle が [ga], and a verb, adjective, or the copula. Table 1 contains an example.

Table 1 PoS of a Self-move Sentence

Subject	Particle	Verb	Translations
猫 Neko	が ga	渡る wataru	The cat crosses over. The cat will cross over.

The sentence kernel is simple and easy to demonstrate. The subject "neko" is followed by "ga". The main role of "ga" is to mark the subject of a sentence, and that role is key. This construction, then, grammatically indicates that the cat moves itself across something—context determines the something—as opposed to being carried across said something by another subject. Also note that self-movement is not passive voice. The cat is acting upon itself. It is not being acted upon by another agent. This idea is more akin to middle voice in ancient Greek.

Other-move sentences provide the grammatical construction required to express actions done by subjects to objects. Therefore, in other-move sentences the subject is acting on something else. Table 2 provides the example.

Table 2 PoS of an Other-move Sentence

Subject	Particle	Object	Particle	Verb	Possible Translations
私 Watashi	が ga	猫 neko	を wo	渡す watasu	I hand the cat over. I will hand the cat over.

In this sentence, the subject is 私 [watashi]—a polite first-person pronoun. Because Japanese has a multi-layered, complex system of honorifics, there are multiple first-person pronouns—one for each layer. Here, "I" performs the action on the object, which is a cat in this case. The receiver of the cat is unspecified in this sentence, but the receiver would be dictated by the context since the receiver is often obvious. Suffice it to say that the entity being moved by the action is an important concept built into Japanese sentences via verbs and supported by particles like を[wo].

The rigid SVO structure of English drastically differs from that of Japanese. This means that any algebraic grammar must be curated to support the Japanese language. Further, the self-move and other-move concept is critical to understanding a Japanese utterance, so a fluent translation must account for verb choice and the corresponding use of particles to correctly discern and translate meaning.

Towards a Diagrammatic Taxonomy of Japanese

This section introduces diagrammatic depictions of self-move and other-move sentences. These diagrams use either the DisCoCat or DisCoCirc methodologies for each grammatical construction, demonstrating the power of diagrammatic reasoning while introducing a small collection of diagrams for use in further research. In time, this small collection can become a true taxonomy. This is important because with topologies of the diagrams identified, any sentence of words with the same PoS are processable regardless of the chosen words. Before proceeding, the underlying grammar must be defined explicitly.

Furthermore, the following investigation of grammar is extensive because understanding intricacies of grammar helps better define the object our DisCo diagrams model. For example, the morphology of Japanese ought to be studied to define the optimum level of qubit granularity. More qubits provide more flexible models but also more computational overhead. The converse is also true. The question, which is another area of potential research, is do translation algorithms provide more fluent outputs when operating at the word level or at the morpheme level? The answer remains to be seen, and the answer, to this and other questions, cannot be discovered without plunging deeply into grammar.

A Pregroup Grammar for Japanese

In pregroup grammars, types are used to calculate whether a group of words, typically a sentence, is either grammatical or not. In practice, left and right-adjoints are paired together with the base type. When this happens, the paired contract to a value of one, cancelling the value out of the calculation. More explicitly, a *contraction* refers to computations on simple-types, represented here by a generic base-type t, of the following forms: $t^l t \rightarrow 1$ and $tt^r \rightarrow 1$. *Expansion* is precisely the reverse: $1 \rightarrow t^l t$ and $1 \rightarrow tt^r$. These are the two fundamental operations performed on pregroup grammars (Cardinal, 2007). Cardinal defines the basic types for a Japanese pregroup grammar as shown in Table 3 (2002). This work contributes an extension of this grammar, novel in the Japanese language, into DisCo—string—diagrams.

Table 3 Cardinal's Pregroup Grammar

Symbol	PoS	Example	English Meaning
π	Pronoun	私 [watashi]	I
$\overline{n}$	Proper name	鈴木 [Suzuki]	The name "Suzuki"
n	Noun	猫 [neko]	cat
a	Adjective	赤い [akai]	red
a_n	Adjectival Noun	好き [suki]	liked
a_v	Adjectival Verb	難しい [muzukashii]	difficult
α	Adverb	新しく [atarashiku]	newly
s	Statement with irrelevant tense	ほら[hora]	Look!
$\overline{s}$	Topic sentence	私は私だ。 [Watashi ha watashi da.]	I am me. As for me, I am me.
s_1	Non-perfective tense	彼が走る。 [Kare ga hashiru.]	He will run.
s_2	Perfective tense	彼が走った。 [Kare ga hashitta.]	He ran.
q	Question	彼が走るか。 [Kare ga hashiru ka?]	Will he run?
c_1	Nominative complement	が [ga]	Marks the subject
c_2	Genitive complement	の [no]	Shows ownership
c_3	Dative complement	に [ni]	Marks indirect objects
c_4	Accusative complement	を [wo]	Marks the object
c_5	Locative or Instrumental complement	で [de]	Specifies the boundaries or circumstances of an action.
c_6	Ablative complement	から [kara]	Specifies movement away from a noun

Note. This table is adapted from Cardinal's 2002 master's thesis. The collection of all these types is sometimes referred to as the "alphabet" or "generators" of the grammar (Bolt et al., 2016; Duneau, 2021).

The types presented in Table 3 seem much more complicated than one might expect given that Japanese words reduce primarily to nouns, adjectives, and verbs (Dolly, 2019). Indeed, while reducing these types to a minimal subset would be a worthy endeavor for further research, that topic is beyond the present scope. It is worth noting that combinations of the base-types from Table 3 are used to represent adjectives and verbs in multiple ways.

Figure 8 introduces Cardinal's partial orders (2002).

$$s_i \to s \to q;$$

$$\bar{s} \to s;$$

$$n_v \to n \to \bar{n} \to \pi;$$

$$a_v \to a;$$

$$a_v \to s_i;$$

$$a_n \to a.$$

Figure 8 Partial Orders of Cardinal's Pregroup Grammar
Note. This image comes from Cardinal's master's thesis (2002).

These postulates show the partial ordering of one base-type to another by means of the binary relation (Cardinal, 2002). This comes into play when selecting pregroup grammar types for implementing a PoS in a conversational grammar. A type on the right, such as *s*, can link with any type to the left of it, such as s_1, and those types will also contract. Using this grammar as the foundation, it is a simple matter to extend these ideas into diagrammatic representations using DisCoCat and DisCoCirc, which also extends beyond the realm of grammar and into that of semantics.

DisCo Diagrams

From this point forward, quantum diagrams are introduced. Everything that precedes this section provides adequate background for understanding the rationale behind these diagrams from a linguistic perspective. Any general observations that indicate some larger principles and heuristics will be highlighted and named as they occur.

Moving the Self

First, consider the simple DisCoCat diagram depicted in Figure 9.

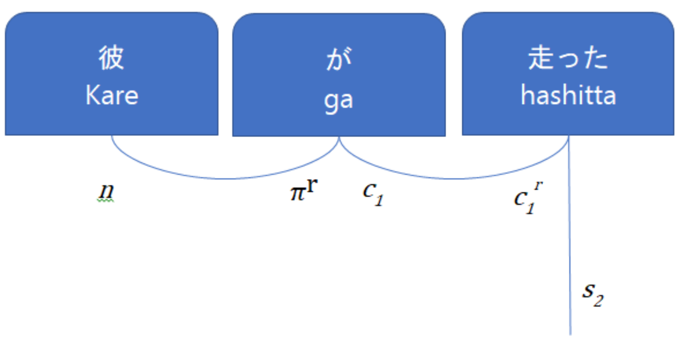

Figure 9 DisCoCat Representation of a Self-move Sentence with a Verb

Figure 9 depicts a string diagram that is sufficient for implementing simple quantum mechanics and algebraic linguistics. This is the first depiction of such in the Japanese language, and this is one of the simplest possible diagrams. Still, it warrants comments. The pregroup grammar provides the mathematical substructure to ensure that the connections are grammatically legal, as has been discussed earlier. The boxes represent the semantic level of understanding beyond the grammar substructure and is implemented via a quantum state (Coecke et al., 2021). Each cup satisfies and symbolizes a unitary matrix and its adjoint being multiplied together and resulting in a 1 value. This is realized by quantum measurements, or Bell tests (Coecke et al., 2021). Its effect is, therefore, negated. The final remaining type is some variety of the s or the q base-types. These demonstrate that the sentence is grammatically legal and semantically sensible. This explanation should sound familiar. It is, in essence, the same explanation offered when discussing underwires in pregroup grammars. To be clear, the major difference is the inclusion of the quantum states and measurements as an additional level of implementation beyond that of grammatical linking (Coecke et al., 2021). Without quantum mechanics, these boxes would simply be boxes. It is astounding that such a simple depiction quantizes linguistics.

Some general observations about Japanese DisCoCat diagrams derivable from Figure 9 follow. First, because Japanese is noun-heavy, π^r simple-types are encoded into particles. Because a particle always succeeds the noun, a right-adjoint type is always used. Further, using the π^r type ensures that the particle can satisfy a standard noun, proper noun, and a pronoun. This observation is known as the *Pi are Numerous Principle*.

Second, the persisting sentence type that remains after the pregroup calculation tends to reside in the verb, adjective, or copula that ends the sentence. The final word in a Japanese sentence drives the meaning. The other words in the sentence relate to the action or statement of being made by this final word. In memory of Cure Dolly, this observation is known as the *Train Engine Principle* since the engine runs at the end of a train, pulling cars along the track (Dolly, 2018a). It is worth noting, however, that there is an exception to this principle to be introduced later. Additionally, it is important to notice that the final word's simple-type definition is flexible. While it can be said, therefore, that a verb or a predicate adjective may have a typical simple-type definition based on its most frequent usage, it cannot be said that the type definition will always be the same since the use of adverbs and additional particles are typically accounted for within the verb or adjective receiving modification.

Third and lastly, since Japanese nouns tend to modify words that immediately follow them and particles attach to the words that immediately precede them, cups typically connect two adjacent quantum states in the diagram. As such, this observation is known as the *Train Car Principle*. Ultimately, this means there are minimal opportunities for graphs to become non-planar when diagramming out sentences in Japanese. All three of these principles follow necessarily because Japanese is an agglutinative language.

Consider now DisCoCirc. Figure 10 introduces a very simple DisCoCirc representation to match Figure 9. Because there is only one simple sentence, this diagram is essentially analogous to the "Hello World" program of DisCoCirc. Indeed, this example could not be simpler and remain functional. "Kare" is the noun, which is represented by the wire. The wire flows through "hashitta", a quantum state, which updates the meaning of "kare" to mean the "he who ran". In this way, a transitive verb updates the noun's meaning as an adjective does. Since the verb here is a quantum state and not an effect, the noun is not terminated and continues to persist, awaiting its next meaning update as the text continues.

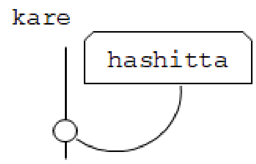

Figure 10 *Simple DisCoCirc Diagram*

Predicate Adjective

Predicate adjectives typify self-move sentences. One of the defining traits of Japanese is the topic marking particle は [ha], which is very powerful and multifaceted. It has the specific function of singling out the topic, but it also has the broader function of denoting difference, contrast, or non-inclusion. The ability of the Japanese speaker to explicitly define a topic allows the speaker to change the *locus of speech*, meaning that the perspective of the situation—where the speech is situated—can be shifted from one person, place, thing, or action to another with great ease without changing the grammatical subject of the sentence containing the topic. The topic, then, functions at a higher level—above the level of a single sentence—than the grammatical subject does. Consider the sentence introduced in Table 4 for an explanation. While this sentence only contains seven words, it is sophisticated enough to demonstrate a crucial point.

Table 4 Self-move with a Predicate Adjective

Noun	Particle	Noun	Noun	Particle	Adj.	Copula	Translation
私 Watashi	は ha	オレンジ orenji	色 iro	が ga	好き suki	だ da	I like orange.

First, notice that there are two particles in this sentence. From left to right, the first is the topic marker, and the second is the subject marker. Obviously, then, the topic and the subject of the sentence are two different entities. In this case, the topic of the sentence is the speaker, and orange-color is the subject of this specific sentence. Again, topics are special because their reach extends beyond the realm of a single sentence and into larger blocks of text. The extent of a topic's reach is often referred to as a comment (Dvorak & Walton, 2014). In this case, the comment is the same as that of the subject since they are both confined to a single sentence example. When multiple sentences are present, this is typically not the case. In a case such as Table 4, the topic defines the perspective of the sentence. The comment that follows after the は [ha] is a sentence unto itself, and it is framed within the view of the topic.

Perhaps comparing progressively more literal translations will make this phenomenon more apparent. Table 5 juxtaposes three potential translations for easy comparison.

Table 5 English Translations of Table 4 Juxtaposed

Simple	Detailed	Literal
I like orange.	I like the color orange.	As for me, the color orange is likeable.

The literal translation is a far cry from the simple. The latter tends to be taught to beginner-level students of Japanese. Notice how the adjectival noun 好き [suki], meaning “likeable”, translates as a verb. Notice also how the subject of the sentence is conflated with the topic in the English translation. In fact, the simple English sentence is slightly more ambiguous. One may wonder if “orange” here is a color or a fruit. A native English speaker would be able to decipher this based on the singular “orange” instead of the plural “oranges”, but perhaps a non-native reader would struggle. The detailed translation resolves the ambiguity, but there is still grammatical confusion regarding the subject, topic, and the translation of an adjectival noun as a verb. Therefore, the literal translation is provided to untie all these conceptual knots: “As for me, the color orange is likeable.” This sentence is not natural in English, but it does demonstrate, via the use of the comma and the preposition “for”, the framing of the sentence from a first-person perspective before proceeding to the body of the sentence. There is no ambiguity now. The subject is orange-color and is described by the predicate adjective “likeable”. This, then, is what is meant by shifting the locus of speech with ease.

Having demonstrated that predicate adjectives are employed to reflect some quality about a subject from the perspective of the topic, consider now the algebraic grammar of such a sentence. This representation is found in Figure 11.

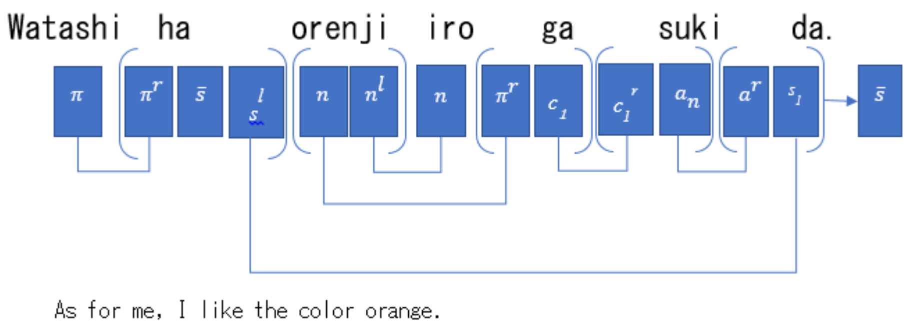

Figure 11 Self-move Sentence with a Predicate Adjective

The analysis pertaining to Table 5 is evident in Figure 11. The “ha” makes the sentence a topical sentence. It also divides the sentence into two pieces like an equal sign does in equations. There is everything that comes before the “ha”, which is the locus of the speech—the perspective from which the rest of the sentences comes or the situation to which it refers. Then, there is the sentence proper containing the subject as marked by “ga”. Notice that this example uses the adjective types from Table 3 and the adjectival version of the copula. This same sentence's semantic meaning would be represented in a DisCoCat diagram as shown in Figure 12.

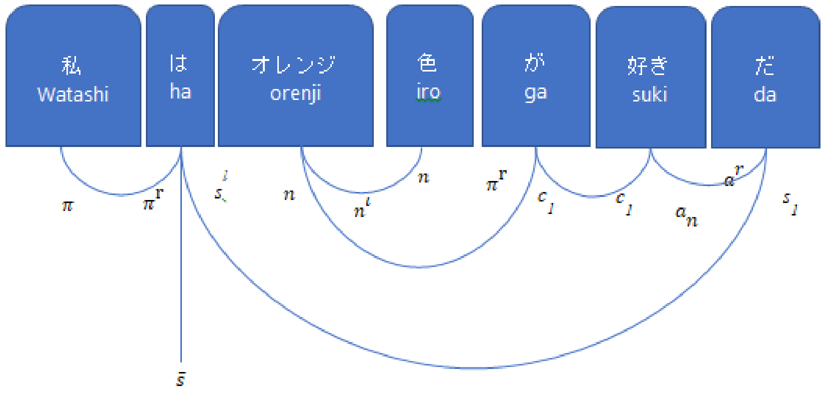

Figure 12 DisCoCat Representation of a Self-move Sentence with a Predicate Adjective

The DisCoCat diagram quantizes the grammar to yield semantics. However, Figure 12 differs from Figure 9. One obvious difference is that this diagram contains an adjective; therefore, the diagram contains adjective types. Specifically, it contains the adjectival noun base-type and the right-adjoint as a simple-type. Adjectives in Japanese generally will be one of three types, and these three types are named based on their function in a sentence. It will be either a noun modifier, a noun, or a verb. The first of these cases is the archetypal use of an adjective. It modifies some person, place, or thing by attributing some quality, limit, count, or the like to it. In the second case, the adjective is actually noun. In this case, な [na] is suffixed to the adjective to modify the word that follows (Hamano, n.d.a). Lastly, the verb case refers to sentences where an i-adjective appears in the predicate position. These adjectives can be morphologically transformed to indicate positivity, negativity, non-perfective, and perfective tenses. Thus, they behave as verbs and are treated as such. Figure 12 represents the adjectival noun case, which has a unique partial order that reduces the adjectival noun to a noun: $a_n \rightarrow n$ (see Table 3; Figure 8). After this reduction occurs, the adjectival noun can be treated like a noun in the grammar in all cases.

The first difference leads logically to the second. Instead of a verb, this sentence contains the copula だ [da]. The copula represents all possible versions of "is", "am", and "are" from the English language in one easy to use word. Thus, it is employed to create a statement of equivalence. Additionally, the polite and honorific forms of the copula raise the politeness level of sentences. In the case of Figure 12, it is functioning only as a statement of equivalence and nothing more. The copula is an interesting case because in extremely casual Japanese, it is possible that the copula might be dropped so that the sentence is easier to say. In this case, it is treated like a particle. Like が [ga], the subject marking particle, だ [da] is present even when it is not spoken by the sheer power of implication. Because Japanese is a high-context language, it is simply assumed to be there even if unuttered. Thus, it is likely that parsing programs would benefit from inserting the missing copula at the end of the sentence when it is omitted, which would provide a degree of uniformity across sentences. This assertion remains yet untested and is an avenue for further research.

Figure 12 seems to violate the heuristic that the sentence type is carried by the final word in the sentence—the Train Engine Principle. As mentioned earlier, there is an exception to the Train Engine Principle, but it is only an exception in part. In reality, it is still true that the sentence in Figure 12 carries the sentence type in its final word; however, Figure 12 also contains a topic marking particleは [ha]. The presence of the topic marker is the crux here. Recall from the discussion on Figure 11 that the topic marker divides the sentence into two chunks, identifying the left-side of the sentence as the topic of the following comment. The right-side of the sentence is its own self-contained sentence even if the subject is implicit and omitted. It turns out, when a topic marker is used, the topic sentence base-type is what remains after the types resolve. Just as it makes perfect sense that the Train Engine Principle asserts that the sentence type resides in the last word of the sentence because it bears the meaning, it is equally true that the topic marker should bear the meaning of a topical sentence. This is because a topical sentence defines a perspective that informs all the sentences that follow until the topic is changed again. It is, therefore, fitting that the topic marker override the Train Engine Principle, since the latter functions at only sentence level. This observation is known as the *Topic Primacy Principle* because the topic marker reigns over a textual unit than a sentence, it supersedes the sentence type carried in the verb.

One final observation on Figure 12 is that it introduces left-adjoint simple-types. Unlike right-adjoint simple-types, which are included to resolve a previously introduced type that has no pairing, left-adjoint types anticipate types to come. There are a couple of instances of this in Figure 12, but a single example should suffice. So, for instance, consider the cup connecting the topic marker to the copula. The topic marker is defined by three simple-types: the right-adjoint of the pronoun, the topic sentence base-type, and the left-adjoint of the sentence. The left-adjoint cannot stand on its own, meaning that the topic marker is anticipating the sentence to follow. This result is again fitting since the topic marker is forecasting a statement that provides information about the topic or is from the topic's perspective.

Next, consider a DisCoCirc diagram. Normally, the idea in DisCoCirc is to take the important nouns, persist them, and specify the relationships between them. These relationships are typically captured by verbs or adjectives, which then link the two nouns together or link directly to the noun respectively. English, however, does not have a topic marker. There is, therefore, no direct parallel in the English literature on how to represent this. Figure 13 suggests a potential approach.

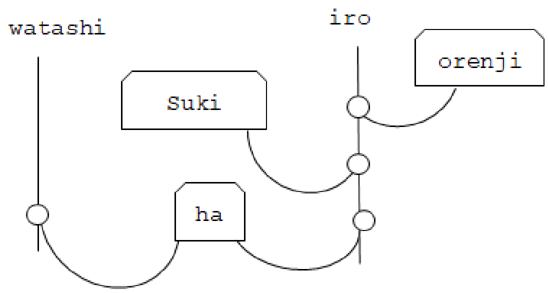

Figure 13 DisCoCirc Diagram with a Topic Marker

Let us consider what Figure 13 conveys. The two selected substantives of importance are "watashi" and "iro". The former means "I", and the latter means "color". This seems reasonable since the interlocutors are likely discussing their favorite colors. It follows that the term color would persist through the discourse and receive meaning updates. Here, the color is described as "orenji", meaning orange, and "suki", or "likeable" in English. The first question is, how to link this meaning back to "watashi". The proposal is to consider the topic marker akin to a transitive verb. Transitive verbs link a subject and an object together and update the meaning of both nouns accordingly. The question is, ultimately, whether this is an accurate representation of what is naturally occurring in Japanese speech. The entirety of the idea expressed in the sentence is clearly to update the meaning of "watashi". After all, each sentence until the topic change is grammatically required to be some comment related to the topic. An interesting problem here is how to ensure the sentences that follow continue to update the topic even though it is not present. One approach is to persist the current topic and add the implied topic back into each sentence when parsing. Next, recall that the sentence containing the topic marker is typically divided into two halves, with the latter half being both a comment on the former and its own independent sentence. For now, including the topic marker in this way is a potential solution that would involve a minimal amount of special consideration when working with the Japanese language. More tightly formulating the solution to this problem, working with larger blocks of text, and testing out potential solutions is an area for further research.

Same Old Verb, Different Forms

Obviously, verbs are another PoS that can anchor a self-move sentence. Figure 9 is one such example. This section introduces the idea of a single verb having self-move and other-move forms. Such a verb applies slight morphological differences to its stem to signify whether the verb moves the self or moves the other. This section discusses the self-move form of one such verb.

To begin, consider Table 6. There's nothing particularly unique or outstanding about this sentence, but it accomplishes two things. First, note that the verb is 決まった [kimatta], which derives from 決まる [kimaru]. This verb means "decide" and is self-moving or intransitive. That means it acts on the subject and not an object in the sentence. Second, Table

6 represents the first use of the adverb type. Its function is, naturally, to modify the use of the verb.

Table 6 Self-move Sentence with a Verb

Noun	Particle	Adverb	Verb	Translation
それ Sore	は ha	もう mou	決まった kimatta	That was already decided.

Next, the algebraic grammar diagram is shown in Figure 14. Again, this is a very straightforward representation. It is worth mentioning a couple things, however. First, observe how the adverb type, represented by an alpha, modifies the verb that directly succeeds it. This is the standard adverbial use case. Second, note that a が[ga] could be used instead of は[ha] in this sentence. Figure 14, as it stands, would be used to change the topic to "sore". If there is no need to change the topic, a "ga" would be used instead. This would change the representation of the verb to that of Figure 15.

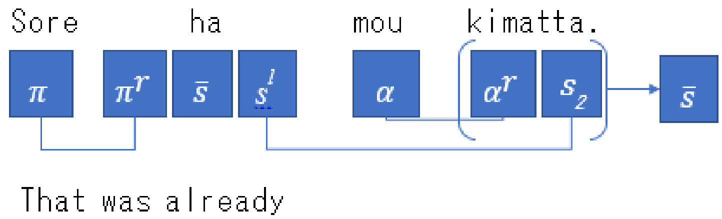

Figure 14 Self-Move Sentence with a Verb

The Figure 15 case proves that self-move verbs can accompany が [ga], or は [ha]. The sentence will ultimately fulfill a different purpose depending on the employed particle. In this case, the c_1^r simple-type must be added to the verb to account for the use of "ga". This distinction is critical when considering fluent translations. Forcing a translation algorithm to discern between topics and subjects is of paramount importance if a translator is going to be truly fluent.

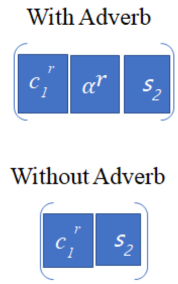

Figure 15 Self-move Verb Options with Subject Marker

Note. This diagram also demonstrates the type definition differences when an adverb is present.

Returning to Figure 14, let us proceed with the DisCoCat representation of this sentence. It is found in Figure 16.

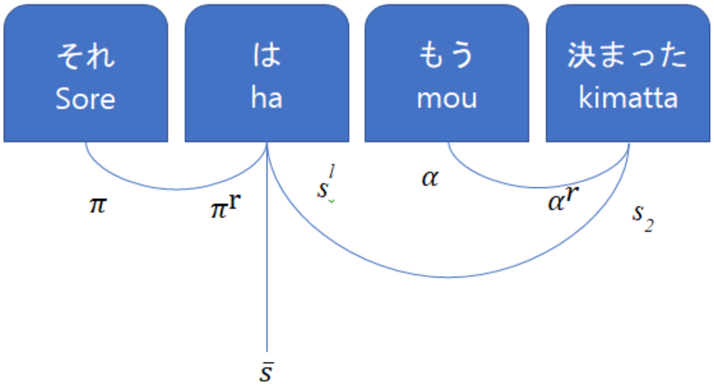

Figure 16 DisCoCat Representation of a Sentence with a Self-move Verb

The DisCoCirc diagram for this sentence is included here for completeness, though this graph would be unlikely to be used. Because "sore" is a pronoun, the noun to which it refers would likely be the noun of importance that would be preserved and updated through the larger discourse. Nevertheless, Figure 17 documents the diagram that would suffice, if required. It is worth noting that this DisCoCirc diagram is structurally equivalent to Figure 10; however, including the adverb as part of the updating process can capture a more nuanced idea of decision.

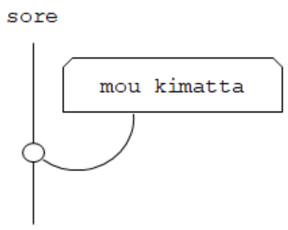

Figure 17 A DisCoCirc Diagram of a Sentence with a Self-move Verb
Note. The self-move verb functions equivalently to an adjective.

Moving the Other

Other-move sentences are more complicated than self-move sentences by their very nature. Every sentence in Japanese requires at least an implicit subject marked by が [ga]. This subject and the subject marker itself are often dropped in casual speech, but even if it is not spoken, it is both grammatically and contextually implied. This is possible due to the high-context nature of the Japanese language. Especially deft speakers can say an incredible amount with a minimal number of words. An other-move sentence not only includes the subject marker, but it also includes the object marker を [wo]. The sentence then, by definition, must include an additional noun, an additional particle, and all the grammatical connections required to support them. An example is provided here to analyze other-move sentence structure in more detail. Furthermore, this section will feature the other-move version of the previously discussed verb 決まる [kimaru], which is 決める [kimeru].

Table 7 introduces the other-move sentence in natural Japanese grammar. In addition to an other-move verb, Table 7 also includes a relative clause. Relative clauses in Japanese are too large a topic to discuss here in detail, but the important thing to remember is that Japanese creates relative clauses be modifying nouns from the right-side with verbs. In this way, an entire sentence worth of meaning can be directly attributed to a noun.

Table 7 Other-move Sentence with a Verb

Noun	Particle	Noun	Particle	Verb	Noun	Particle	Verb	English Translation
かれ Kare	は ha	薬 kusuri	を wo	付ける tsukeru	こと koto	を wo	決めた kimeta	He decided to apply the medicine.

Table 7's sentence is about a man who decided. The content of that decision is made explicit by the relative clause "kusuri wo tsukeru koto". One way to translate this idea more literally into English is to refer to it as an event. Transforming a verbal idea into an explicit noun is one of the primary roles of こと[koto] in Japanese. Table 8 is provided to help make the function of "koto", meaning "thing", "matter", "situation", or "event", easier to grasp. Based on Table 8, it is easy to see the function of "koto" in Table 7, though the literal translation is very unnatural in English. "Koto" takes a clause with a verb and makes it a relative clause by nominalizing said verb—making it a noun in the sentence. Because verbs cannot accept logical particles as suffixes, there must be some way to make a verb into a noun to fulfill grammatical duties in conjunction with particles. This is done in English using "-ing" as a suffix. In a Japanese sentence, it is often done using "koto", though the particle の[no] can also perform this function and sounds more natural in many instances. Here, the focus is "koto".

Table 8 Juxtaposed Translations of Table 7's Other-move Sentence

Literal English Translation	Fluent English Translation
As for him, he decided the apply the medicine matter.	He decided to apply the medicine.

Table 9 provides a direct comparison between the self-move and the other-move versions of the sentence-ending verbs in Table 6 and Table 7. Comparing these two verbs directly is instructive.

Table 9 Direct Comparison of Self-move and Other-move Forms of a Verb with Same Stem

Self-Move Form	Other-Move Form
決める kimeru	決まる kimaru

There are a couple of things to notice in Table 9. First, note that the kanji character used in both words is the same. The role kanji is to convey the core meaning of the word and to mark the word's stem. A word can contain multiple kanji, or the kanji is supplemented by kana. This latter case is what is done in adjectives and verbs. The attached kana characters shape the meaning of the verb. Second, the middle character in both words begins with the "m" sound. The Japanese syllabary consists of columns of five vowel sounds and the consonants that support the vowel in a legal utterance. In Japanese, many verbs are built on the same kanji which differ only in the middle syllabet's vowel sound. This is a telltale sign that one is the self-move form of a verb, and the other is the other-move version. This is indeed the case in Table 9. Another common difference is whether the final kana character is a す[su] or a る[ru]. A classic example of this difference would be 返す[kaesu] and 返る[kaeru]. The former is typically other-move and the latter is self-move (Dolly, 2018b). While it is usually true that the "e" sound signals an other-move form and the "a" sound signifies a self-move, this is not always the case. This is one of the few places where Japanese is not consistent (Dolly, 2018b; Hamano, n.d.b). The use of particles is, again, the arbiter of whether a verb is self-move or other-move.

Next, let us move to the algebraic grammar analysis of Table 7. Figure 18 does just that.

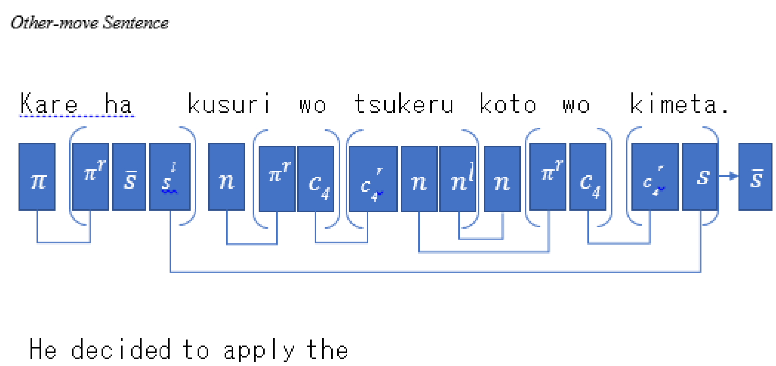

Figure 18 Other-move Sentence

Because this sentence is topical, it also breaks down into two halves like an equation. The right-half is a fully grammatical sentence with an implied が [ga] since the subject and the topic are equivalent, namely "kare". The relative clause in the sentence uses the noun こと [koto] to nominalize the clause, and the particle を [wo] is suffixed onto "koto" to indicate the accusative case. The verb "tsukeru" relies on a useful type definition strategy to connect anything to a succeeding noun. This strategy, known as the *Noun Sandwich Principle*, relies on the left-adjoint's ability to forecast a type to force the consecutive noun simple types (see Figure 11). This sentence contains the accusative particle twice. Since the accusative particles exist in separate clauses, there is no ambiguity. The accusative particle that follows the "koto" links to the other-move verb, namely 決めた [kimeta].

The next step is the DisCoCat diagram in Figure 19. It is a perfect extension of the pregroup grammar of Figure 18 into the realm of semantics.

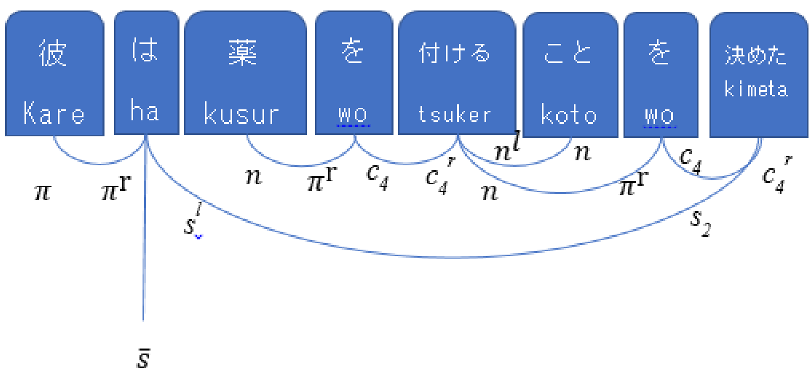

Figure 19 DisCoCat: Other-move Sentence with a Relative Clause

Figure 19 demonstrates several of the principles introduced before. The topic markerは [ha] again demonstrates Topic Primacy. In this example, however, there is a large leap of five words to the main verb—the would-be train engine. Again, because the sentence is topical, the Train Engine Principle is superseded. The Train Car Principle is evident as there are many cups between adjacent quantum states. The Noun Sandwich Principle is also evident. It is here applied to join the other-move verb 付ける [tsukeru] to the nominalizer こと [koto]. The noun sandwich has an intriguing quality in that it relies on a cup that skips over a noun to connect to the subsequent particle. This gives the effect of suffixing the particle onto the verb in Figure 19, which is precisely what "koto" intended to do. Suffice it to say that the DisCoCat representation is perfectly capable of representing self-move and other-move sentences. It is instructive to compare the diagrams with one another to pictorially show the underlying grammatical mechanisms at play and how these mechanisms inform the topology of the semantic diagrams. This is particularly true when comparing diagrams containing the self-move and other-move versions of the same base verb. Ultimately, the choice of verb form determines whether the train cars can be towed well; therefore, this type of consideration is of utmost importance when musing over the idea of fluency.

Lastly, Figure 20 provides the DisCoCirc diagram. This diagram is representative, meaning it is one possible valid diagram. It is very likely that こと [koto], would not be considered a primary noun because it is used primarily out of grammatical necessity.

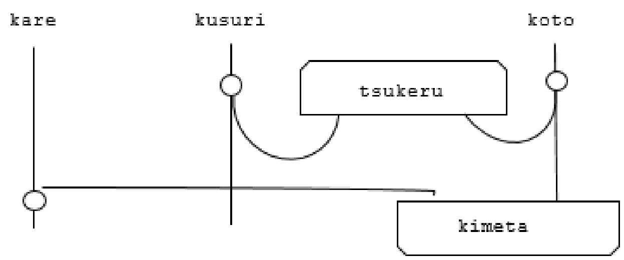

Figure 20 DisCoCirc Diagram of an Other-move Sentence

Nevertheless, for this example, “kare”, “kusuri”, and “koto” are chosen as the primary nouns, and each is granted its own wire. These nouns mean “he”, “medicine”, and “thing” respectively. Because of the realization that the “koto” wire may not be permanent, it ends by feeding directly into “kimeta”, the other-move verb that links with “kare”. This termination is depicted graphically by mirroring the quantum state across a horizontal cross section. This is the diagrammatical representation of an effect—a quantum measurement—which in DisCoCirc represents an imposition of a subject onto an object (Coecke, 2020). Reasoning up from the bottom of the diagram, a rough translation of the bottom and left portions would be something like “he decided the thing”. The quantum effect used to represent “kimeta” indicates that deciding something in this graph terminates the wire. The upper and right portions link “kusuri” through “tsukeru” to “koto”. This, clearly, is the portion of the diagram that represents the relative clause. The “thing” being discussed here is the “application of medicine”. Thus, when both sides are taken as a whole, the upper-right-side is completed first. This is represented by the verb “tsukeru”, meaning “apply to something” in this case., being listed higher than “kimeta”, which means “decided”. So, the meaning of “koto” is updated first, then the meaning of “kare” is updated last. “Kare” and “kusuri” persist farther into the narrative—are outputted through the sentence as represented by a process. “Koto”, on the other hand, does not. This termination of noun wires is an important distinction between self-move and other-move sentences. The former applies attributes to the subject, while the latter acts on objects.

Conclusion

In a world where quantum computers are capable of error correction, translation devices using QNLP will surpass classical machines with standard methods of NLP; therefore, the power of quantum computers is critical to achieving unprecedented translation accuracy and even fluency. This research provides groundwork for application of QNLP to Japanese by providing a novel extension of the language's pregroup grammar.

First, category theory-based approaches to QNLP show promise because they can represent complex mathematical concepts and calculations simply with boxes and wires. Furthermore, category theory naturally extends pregroup grammars, making quantum calculations achievable for algebraic linguists. Diagrams, then, democratizes problems reducible to quantum mathematics.

DisCo research has focused on the English language. This leaves the research susceptible to bias. As a logical and low-context language with a strict word order, it differs dramatically from high-context languages with grammatical fluidity. Studying Japanese then, precisely because it differs wildly from English, may uncover potential oversights. The present work addresses self-move and other-move verbs, their supporting grammatical structures, and the string diagrams representing their semantics. Additionally, it is a primer on the behavior of particles in DisCoCat and an initial speculation into that of DisCoCirc.

The study of DisCoCat diagrams yielded novel contributions in the form of observable topological principles of Japanese language diagrams. To provide the same for DisCoCirc requires investigation of much larger bodies of text. These DisCoCat principles follow:

1. The Pi are Numerous Principle: Diagrams of any degree of complexity contain many pronoun types, represented by π. These are mainly manifested as the right-adjoints of π, shown as π^r , hence the wordplay in choosing "are" instead of "is". The latter is grammatically correct but much less fun.
b. The Train Engine Principle: The final word of a sentence is the mover of the sentence. The *s* base-type is encoded into this final word. It is, therefore, like a train engine pulling a series of train cars. The exception to this rule is topical sentences, which have their own overriding principle.
c. The Train Car Principle: Modification flows from left to right, often in single hops, like how train cars link one to another to form a proper train. The exceptions to this principle are topical particles and adverbs, which have more positional freedom. Nevertheless, this general observation is a foundational heuristic of these graphs.
d. Topic Primacy Principle: Particles that function at the topic level, like は [ha], supersede the Train Engine Principle. The reason for this is the topic affects a larger portion of the text—the comment (Dvorak & Walton, 2014).
e. The Noun Sandwich Principle: Words functioning as prefixes are encoded with nn^l and joined by a *n* base-type from the right by a cup. The result is that three noun types are used together across two words, creating a sandwich of noun types.

This work also recommends many avenues for continued research. One first-order concern is the granularity with which diagrams are constructed. Japanese contains not only words but morphemes. It is not obvious whether constructing diagrams at the word-level or the morpheme-level produces more accurate and fluent translations. This becomes particularly important when working with causal and passive verbs as morphemes are critical to correctly parsing their meanings. Concerning parsing generally, Japanese, as a high-context language, frequently drops crucial grammatical elements when spoken, including the subject marker が [ga]. Parsing methods are a crucial preprocessing step of DisCo diagrams. Implied elements may require specification during preprocessing.

Obviously, other diagrammatic representations, like ZX-calculus, exist. Surely topological heuristics exist in these representations too. It follows that typical quantum circuit topologies remain to be demonstrated based on this work. Additionally, other algebraic grammars remain to be tested. Alternative grammars may hide surprising benefits. Further, optimization of Cardinal's alphabet may be possible.

Of course, there are other grammatical constructs to be studied. Adverbs, adjectives, and relative clauses are mentioned here, and this work would serve as a good foundation to investigate them in detail. Studying implications is another path forward. An example is the choice of こと[koto] or の[no] for nominalization. Naturally, there is also logical negation and how to represent it in Japanese. Negation relies on the adjective ない [nai], which functions differently than the "not" of English.

Much remains to be said about particles in DisCoCirc diagrams. Japanese also has layers of politeness that are heavily informed by worldly context. Incorporation of worldy context into translations for determining proper levels of politeness or providing negation is a must (Rodatz et al., 2021). Fluency cannot be attained without addressing this concern. Any of these avenues could be the subject of experimentation with publishable results. The finer points of quantum translation will require quantitative and qualitative study to tune algorithms and processes.

References

Abbaszade, M., Salari, V., Mousavi, S. S., Zomorodi, M., & Zhou, X. (2021). Application of quantum natural language processing for language translation. *IEEE Access*, *9*, 130434–130448.

Al-Mehairi, Y., Coecke, B., & Lewis, M. (2017). Categorical compositional cognition. *Quantum Interaction*, *10106*(QI 2016), 122–134. https://doi.org/10.1007/978-3-319-52289-0_10

Bolt, J., Coecke, B., Genovese, F., Lewis, M., Marsden, D., & Piedeleu, R. (2016). Interacting conceptual spaces. *Electronic Proceedings in Theoretical Computer Science*, *221*, 11–19. https://arxiv.org/abs/1608.01402

Cardinal, K. (2002). *An algebraic study of Japanese grammar* [Master's thesis, McGill University]. eScholarship@McGill. https://escholarship.mcgill.ca/concern/theses/m326m3733

Cardinal, K. (2007). A pregroup analysis of Japanese causatives. In *Pacific Asia Conference on Language, Information and Computation* (pp. 96–104). The Korean Society for Language and Information (KSLI). https://aclanthology.org/Y07-1009

Chen, A. (2020). *NLP Pipeline*. National Taiwan Normal University. https://alvinntnu.github.io/NTNU_ENC2045_LECTURES/nlp/nlp-pipeline.html#post-modeling-phases

Coecke, B., de Felice, G., Marsden, D., & Toumi, A. (2018). Towards compositional distribution discourse analysis. *Electronic Proceedings in Theoretical Computer Science*, *283*, 1–12. https://doi.org/10.48550/arXiv.1811.03277

Coecke, B., de Felice, G., Meichanetzidis, K., & Toumi, A. (2020). Foundations for near-term quantum natural language processing. arXiv. https://doi.org/10.48550/arXiv.2012.03755

Coecke, B., de Felice, G., Meichanetzidis, K., & Toumi, A. (2021). How to make qubits speak. arXiv. https://doi.org/10.48550/arXiv.2107.06776

Coecke, B., & Kissinger, A. (2017). *Picturing quantum processes: A first course in quantum theory and diagrammatic reasoning*. Cambridge University Press.

Coecke, Bob. (2016). From quantum foundations via natural language meaning to a theory of everything. arXiv. https://doi.org/10.48550/arXiv.1602.07618

Coecke, Bob. (2020). The mathematics of text structure. arXiv. https://doi.org/10.48550/ARXIV.1904.03478

Dolly, C. (2018a, March 25). *Lesson 1: Japanese made easy! What schools never teach. The core Japanese sentence -organic Japanese* [Video]. YouTube. https://www.youtube.com/watch?v=pSvH9vH60Ig&t=138s

Dolly, C. (2018b, June 23). *Lesson 15: Transitivity- the 3 facts that make it easy. Transitive/intransitive verbs unlocked* [Video]. YouTube. https://www.youtube.com/watch?v=ELk1dqaEmyk

Dolly, C. (2019, August 24). *Secrets of the で [de] particle. Why do we say みんなで行く [minna de iku]? and 世界で一番[sekai de ichiban]?* | *Lesson 55* [Video]. YouTube. https://www.youtube.com/watch?v=OiKgudW9xB8

Duneau, T. (2021). Parsing conjunctions in DisCoCirc. In *Proceedings of the 2021 Workshop on Semantic Spaces at the Intersection of NLP, Physics, and Cognitive Science (SemSpace)* (pp. 66–75). Association for Computational Linguistics. https://aclanthology.org/2021.semspace-1.7

Dvorak, J. D., & Walton, R. D. (2014). Clause as Message: Theme, Topic, and Information Flow in Mark 2:2-12 and Jude. *Biblical and Ancient Greek Linguistics*, *3*, 31–85. https://www.academia.edu/8695843/Clause_as_Message_Theme_Topic_and_Information_Flow_in_Mark_2_1_12_and_Jude?sm=b

Hall, E. T. (1976). *Beyond culture*. Anchor Press.

Hamano, Shoko. (n.d.a). *Visualizing Japanese grammar: Unit 5: Adjectives*. Gwu.edu https://www2.gwu.edu/~eall/vjgnew/05adjectives/05adjectives.html

Hamano, Shoko. (n.d.b). *Visualizing Japanese grammar: Unit 7: Transitivity 1*. Gwu.edu https://www2.gwu.edu/~eall/vjgnew/07transitivity1/07transitivity1.html

Harris, Z. S. (1954). Distributional structure. *WORD*, *10*(2–3), 146–162. https://doi.org/10.1080/00437956.1954.11659520

Lambek, J. (1997). Type grammar revisited. In A. Lecomte, F. Lamarche, & G. Perrier (Eds.), *LACL '97: Selected Papers from the Second International Conference on Logical Aspects of Computational Linguistics* (pp. 1–27). Springer-Verlag. https://dl.acm.org/doi/10.5555/645666.665029 a

Lambek, J. (2008). *From word to sentence: A computational algebraic approach to grammar*. Polimetrica. https://books.google.com/books/about/From_Word_to_Sentence.html?id=ZHgRaRaadJ4C

Lorenz, R., Pearson, A., Meichanetzidis, K., Kartsaklis, D., & Coecke, B. (2021). QNLP in practice: Running compositional models of meaning on a quantum computer. arXiv. https://doi.org/10.48550/arXiv.2102.12846

Meichanetzidis, K., Gogioso, S., de Felice, G., Chiappori, N., Toumi, A., & Coecke, B. (2021). Quantum natural language processing on near-term quantum computers. *Electronic Proceedings in Theoretical Computer Science*, *340*, 213–229. https://doi.org/10.4204/EPTCS.340.11

Miyagawa, S. (1999, October 13). *The Japanese language*. Web.mit.edu. https://web.mit.edu/jpnet/articles/JapaneseLanguage.html#writing

O'Riordan, L., Doyle, M., Baruffa, F., & Kannan, V. (2020). A hybrid classical-quantum workflow for natural language processing. *Machine Learning: Science and Technology*, *2*(1). https://doi.org/10.1088/2632-2153/abbd2e

QNLP. (2019, December 19). *Why NLP is quantum-native, and beyond! [Video]*. YouTube. https://www.youtube.com/watch?v=6-uKZN5_eAU

Rodatz, B., Shaikh, R., & Yeh, L. (2021). Conversational negation using worldly context in compositional distributional semantics. arXiv. https://doi.org/10.48550/arXiv.2105.05748

van de Wetering, J. (2020). ZX-calculus for the working quantum computer scientist. arXiv. https://doi.org/10.48550/arXiv.2012.13966

Zeng, W., & Coecke, B. (2016). Quantum algorithms for compositional natural language processing. *Electronic Proceedings in Theoretical Computer Science*, *221*, 67–75. https://doi.org/10.4204/EPTCS.221.8

Paper Received December 14, 2022; Accepted March 20, 2023; Published May 2, 2023