# A Preliminary Study of
# Functional Parts as Roles

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**Abstract.** We study the generic notion of part as used, for example, in common-sense studies and in natural language, and rephrase it in terms of a role theory. The goal is not to redefine the parthood relationship but to reinterpret it within a richer theory via ontological analysis. By embedding parthood into role theory, it becomes possible to highlight the unifying characteristics of the notions of part and role, and to refine and enhance the theory of parthood to face anew some traditional puzzles.

**Keywords.** parthood, role, function, functional part

## 1. Introduction

Ontology relies on three structural relations: subsumption (formally written *is_a*), parthood (*part_of*) and instantiation (*instance_of*). All these relations have been axiomatized and are formally well understood [3,9]. Other notions have a particular status in ontology because of their general applicability [1]. Among these, the notion of function is widespread across all disciplines and is used to highlight special interactions across (simple and/or complex) entities with the aim of clarifying their pivoting status. Using functional narratives, we can build an integrated framework with which to make sense of the world, see e.g. [10].

The interplay between the structural relation of parthood and the explanatory character of functionality has been at the center of ontological discussions for instance to explain surprising irregularities in natural language like the failure of transitivity of the parthood relation [2,3]. We believe that the same interplay between parthood and functionality allows us to investigate another fundamental issue which is stated by this basic ontological question: *what is a whole?*

The understanding of wholes has always been an intriguing and difficult challenge. For this reason, the study of the parthood relation has soon moved to a cognate but simpler question: *given a whole, what are its parts?* This second problem concentrates on wholes as (at least conceptually) decomposable entities. The view, although natural

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for most everyday objects, changes the perspective and introduces wholeness as a relative notion: any entity, part of a whole, becomes itself a whole when the entity is, conceptually or practically, isolated from its whole. In this sense, a car is an whole that has an engine as a part. The engine itself is a whole, no matter whether it has been removed from the car or not. The engine has its own parts, for instance, the pistons. The piston is itself a whole and has its own parts, e.g. the piston ring and the connecting rod which is connected to the crankshaft along its main axis.[3]

In the case of the crankshaft, the parts are not materially separated from the rest of the object, there is no material discontinuity. Parts that are identified without physical discontinuity are called *fiat parts*, the others *bona fide parts* [4]. From the examples, it is clear that almost anything can be separated in parts (e.g. physically extended objects can be divided along their spatial dimensions and temporally extended objects along the temporal dimension) making the parthood relation quite broad.[4] Subsequently, researchers have attempted to characterize wholes by imposing general criteria on the parthood relation. This leads to study the parthood relation as a tool for object *composition*, reversing the initial focus of parthood, i.e., object (or better, whole) *decomposition*. By embracing this view, one finds natural to conclude that some objects can be seen as 'parts' of an object A in so far as they, considered together, identify the object A (namely their union) as a whole. The subsequent step is to search for the conditions that give parthood this constructive role and to develop formal theories to give logical grounds to the different views of parthood with their accompanying sets of constructive principles. This line of research has turned the problem of using parthood to define wholeness into the problem of understanding what the term 'object' means across the spectrum of the possible parthood relations [5,6,7].

We propose to turn away from the latter view of parthood, i.e., that of a tool with which to analyze the structure of objects in terms of parts. We argue that a different view can be developed by focusing on the connection between wholeness and functionality, where functionality is understood broadly: a functional role [10] as well as a capacity [14]. Briefly, we aim to investigate the claim that an entity is part of a whole because it *contributes* to its being a whole. This view, which we start to study in this paper, leads to introduce functional roles in the study of the relationship between parts and wholes [3, 11].

Structure of the paper: Section 1 presents motivating examples. Section 2 introduces subtypes of functional parts which in Section 3 are explained in terms of a role theory. Section 4 discusses some answers to the questions raised in Section 1 and Section 5 adds concluding remarks.

## 2. Paradigmatic Examples

### 2.1. Schools and Restaurants

It is natural to say that a teacher of a school (not the person *per se* but the role-holder, i.e., the person playing the teacher role) is part of the school. We could say that a student is

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[3]We have in mind a combustion engine. Similar examples hold for electric engines and standard artifacts as well.

[4]The classical example of an object without parts is a geometric point in the Eucledian space since its identifying characteristic is that it has no (proper) part.

also part of the school but we believe this latter claim has a weaker strength. The reason, we surmise, is that a teacher of the school system is an active participant for generating the service that the school provides, while the student is a user of that service. The lack of students does not affect the capability of the school to provide the service, the lack of teachers does. This distinction between the active and the user roles is not specific to schools. Consider the chef and the customer of a restaurant. They are, generically speaking, parts of the restaurant system. However, the chef is necessary to the restaurant to have the capability to provide the service. The presence of the customer is needed to perform the service but does not affect the capability of the restaurant. This difference is strong to the point that it is cast in the different formal contracts that define on the one hand the chef and teacher roles, and on the other the customer and the student roles in these systems: an employee contract vs an (often implicit) service contract. If we use plain mereology to analyze the parts of schools and restaurants, we would conclude that students and customers are on a par with teachers and chefs. After all, these are all parts designed to coexist for the functional relationship of these complex systems to exist. The difference, as we noticed, is based on the specific functional roles that these elements play and that mereology ignores. Note that, since a newly open restaurant is a restaurant even though it has no customer (and perhaps will never have), a defender of mereology could claim that customers are not part of the (newly open) restaurant since there are no such entities yet. Of course, the problem remains since they would become part of the restaurant as soon as someone starts to play the customer role.

Sometimes the asymmetry of the pairs teacher-school vs student-school and of chef-restaurant vs customer-restaurant is explained by looking at the stability of the first players (teacher vs student, chef vs customer) over time. However, the next example contradicts this conclusion.

### 2.2. Bike Riders and Car Engines

The previous examples showed that there are different types of parts and that not all parts are equally relevant to their whole. From the examples one might think that the asymmetry between these parts is due to the length of the period in which they are part of the whole. After all, the teacher tend to be part of the school (or of the school system) for periods considerably longer than the students. Similarly for the chef and the customers. Although the temporal factor might contribute, we can show that it is not central. Consider a car and a bike. The engine of the car and the cyclist of the bike play the role of driving force generators for these artifacts: a car needs an engine and a bike needs a human rider to function. It is common to assume that a car engine is part of the car on which it is mounted. Since the engine is part of the car, by similarity we should conclude that the cyclist is part of the bike. Yet, this does not sound correct. Is this explained by the fact that the engine is typically always mounted on the car while the cyclist only when the bike is used? In the case of a motor boat with a detachable engine, we still have that the engine is part of the boat even though the boat's engine is typically removed from the boat when not used. The bike and the boat examples are analogous on the temporal aspect while the boat, the car and the bike are analogous on the functional aspect. This suggests that the temporal factor is not critical for the parthood relationship in these cases. Having ruled out the temporal factor, we still need to explain the intuitive difference in the analysis of the car and the bike cases.

## 2.3. Electric Fans and Oil Radiators

Some entities are necessary for a device to work properly but we do not consider them as parts of the device. Consider an electric fan. Although it needs air to function, air is not part of the electric fan. Instead, when we talk of an oil radiator the liquid in it is considered part of the radiator. Is this because the oil is installed in the radiator from the beginning? Yet, the bike and car examples told us that temporal aspects are not relevant. Is it because the radiator is not supposed to be open and thus the liquid cannot be substituted easily? If we include as parts the objects that are hard to remove and necessary for a device to perform its function, we should conclude that air of an electric fan is a part of the fan as the oil is part of the radiator. This conclusion is however problematic. As we have seen, natural language gives some indication on how the notion of part should be understood and mereological part, i.e., the notion of part as modelled in mereology, is too restricted to make sense of these different meanings. We thus decided to introduce a broader (richer) view of parthood to find general guidelines that can help to identify wholes and their parts. In this paper we start this investigation by a first analysis of the relationships holding among objects and parts.

## 3. On Being Parts

### 3.1. Wholes, Objects and Parts

When we talk about a whole, we usually refer to entities like artifacts, events or even facts. These examples pinpoint complex entities which, to be understood, need to be identified together with (at least) some of their components. Briefly, these entities are naturally seen as made out of parts and the parts themselves are understood as independent entities that, combined in a particular way, make up those wholes: the components of the artifact, the temporal parts or participants of an event, the entities of a fact and their (relative) status. At the same time, one has that those parts exist as such only in the context of that very whole. That is, they are objects that are parts when combined in a particular way, and they are parts that are identified because of that very whole. From this second viewpoint, the whole and its parts are interdependent and the parts might be independent at most from each other.

Leaving aside atomic wholes, in formal logic one can decide which view to take. A whole can be logically defined via its constituents which are prior, i.e., primitives or entities previously defined. In this case, the logical definition cannot characterize the constituents as parts of the whole without first stating their existence as full objects. These entities exist independently from their status as parts. In the applied sciences one often takes the opposite stand, which is also formalizable in logic: first the existence of an entity (a system) is given and then, via the application of some criteria, its parts are isolated, if any, and identified. These parts thus exist primarily as parts of the whole, they depend on it. A third option is neutral in terms of priority: it assumes that objects exist and that some objects are equals to the (mereological) sum of some set of other objects. The latter is formalized in standard extensional mereology.

Foundational studies have been traditionally based on the first approach: assume a set of atoms exist, new entities are obtained by combining those. This is the view taken,

for instance, in mathematics via set-theory. The study of parthood in the literature has mostly concentrated on the last perspective: objects are entities which can be atomic or combinations of other objects without one being prior to the other. The remaining view, the use of parthood as a dissecting tool, is the view that we aim to investigate here. With this goal in mind, we start establishing a sharp distinction between an entity which is not the subject of parthood analysis, a *bare-entity* so to speak, and the standard notion of entity, i.e., an entity to which the relationship of parthood applies and, because of this, is necessarily a whole. Since we claim that bare-entities are distinct from the entities in the standard sense, we need to characterize what the difference is. Our proposal is to model the distinction via the framework of a role theory [13, 15]. In the role theory, an entity (a bare-entity) becomes a *role-holder* by playing a role. An entity playing a role is a (role) *player*, and an entity that could play the role but is not, is said to be a potential *player* [15]. A bike wheel, for instance, is an example of a potential player for the front wheel. The front wheel is a role defined by a bike frame. Thus, given a bike frame, there are two wheel roles: front wheel and back wheel. A wheel mounted on the front side of a bike is a role-holder since it plays the front wheel role for that bike. A wheel is an independent entity just like the bike, it can be produced following a design specification given in a product model without reference to any specific bike. A front wheel instead can be defined only in the context of its whole, the bike frame. The definitions of role and role-holder capture this distinction in their generality: the bare-entity is a *(potential) player* of the role of part (part-role) while the entity itself, being the entity that is *actually playing* the role of part, is the *role-holder* (part-role-holder) for that very role. Before investigating the consequences of this approach, let us first look at the impact of this distinction on the common-sense understanding of different kinds of parthood relations.

*3.2. Kinds of Wholes and Kinds of Parts*

The distinction between a part as role-player (wheel) and part as role-holder (front wheel) is rather ontological in nature in the sense that it is driven by general considerations and applies across the parthood family of relations. If one looks at the parthood spectrum more closely, a few notions can be isolated [3] beyond the classical examples of spatial and temporal parts dealt with in standard mereology discussions:

(1) **component** (in the context of devices and systems): these parts are usually distinguished in terms of their functional contribution to a whole, and the whole is the result of their composition and physical interconnections. E.g., water pipes and a water circuit, electric components and electromagnetic induction system;

(2) **portion** (in the context of mass objects): these parts have no clear boundary and are intrinsically dependent on a property or quality of the whole. E.g., a portion of (the extension of) a wall, a portion of (the size of) a cake;

(3) **material**: these parts are distinguished in terms of constitution, they provide the substratum for the existence of the whole and may be coextensive with it. E.g., the clay of a vase, the water of the river;

(4) **feature**: these parts have no clear boundary, like portions, but differ from the latter because they have a clear location. E.g., the corners of a table, the bumps of a road.

These examples suffice to highlight the variety of notions of parthood even if we restrict only to those verbalized in natural language. The distinction of these and other kinds of parthood relations can make justice of apparently contradictory properties like transitivity which holds for spatial, temporal and stuff parts and fails for functional and qualification parts [5,6,7]. In our view, these differences are not special cases, they are the natural outcome of the interaction between mereology and role theory. In the following, we concentrate on the notion of functional part or component. Yet, most of our considerations are generally applicable.

We propose to define functional part and its relevant subtypes as follows.
**Definition of functional part**: Given an entity A and a behavior B of it, a functional part for that behavior is a mereological part of A that, when installed in A, has a behavior that contributes to the behavior B of A.

**Subtypes of functional part**
Given an entity A and a behavior of it, then

a. A functional part is said to be a ***genuine part*** of A if from the structural point of view it is installed at the right position in A. Example: the wheel installed in the front of a bike (front wheel) and a car engine installed in the expected position are genuine parts. Neither an engine that is uninstalled from the car for repairing nor an arbitrary engine of the same type is a genuine part of that car.(See (d))

b. A functional part is said to be a ***replaceable part*** of A if it is installed and can be substituted by another entity of the same type changing neither the identity of entity A nor its behavior for which it is a functional part. Example: a wheel installed as a front wheel is a replaceable part. Note the difference between the wheel installed as front wheel of the bike and the front wheel itself of the bike: the front wheel is a new dependent entity with the property of being at the specified position and hence non-replaceable. The wheel installed as the front wheel, instead, is replaceable. Also, the bike frame is a non-replaceable part of the bike since it is essential for the bike's identity.

c. A functional part is said to be a ***persistent part*** of A if it exists at any time as far as the bike exists. It is a specific position with the specification of A for a physical part of A. Example: the power-generator position of the bike is a persistent part of the bike. Note that this subtype of parthood is specific to the entity's type. No physical part of the bike, even independently of its essentiality or not to the bike, is a persistent part according to this definition.

d. A functional part is said to be a ***constituent part*** of A if it has been determined to be used as a part of A independently of whether its specific position has been assigned or not. In the typical case it is a part which has only a generic position in the entity A: essentially any entity in the mereological sum of an artifact's components. Note that an engine uninstalled from the car for repairing is also a constituent part as is the bike rider for the bike when it gets off the bike for a break.

These four specializations of functional part provide us with enough vocabulary for explaining various critical examples discussed in the literature. For example, the fact that the empty functional role is a functional part even if the functional role player is

absent. In the terminology just introduced, the former is a *persistent part* and the latter a *replaceable part*. From the definition, it also follows that an entity playing only an operand role for the whole is not a functional part of the whole. Thus, the water is not a functional part of the boiler, the air is not a functional part of the electric fan and the rails are not a functional part of the train. The theoretical grounds for these distinctions rest in the theory of roles [13].

### 3.3. Interpretation of Functional Parts in Terms of the Role Theory

We now revisit the interpretation of the functional part subtypes in terms of the role theory elements [13]

a. A genuine part is a role-holder, i.e., the entity that has a role enriched with the new properties that are due to that role. Thus, a genuine part is a part that satisfies the specifications of the role to which it is appointed and is also playing the role. E.g., a teacher while at school although not necessarily in class but not if at home on sick leave. Similarly, an installed car engine no matter whether turned on or off.

b. A replaceable part is the bare-entity which is the player of a genuine part,, thus, it is an entity that is selected for the role and that satisfies the role specifications. E.g., Tom listed by a school as a potential teacher there (e.g., for possible teacher substitutions) and a wheel that satisfies the requirements to be the front wheel (to play the front wheel role) of a given bike.

c. A persistent part is a role, independently of whether it is being played or not. It is understood as a location within A together with the specification, i.e., a set of constraints that explicitly refer to A as a system. E.g., a teacher role, a math teacher role, a front wheel role, a power generator role of a car, etc. are all such roles that intrinsically exist in the respective systems. Let us clarify further this kind of parts. Fix a physical artifact as the system A. Any part of it has structural specifications including interdependences between parts in terms of the structural perspective. In addition to it, functional parts have functional specifications (e.g., causal relationships among parts' behaviors and the system behavior) to be fulfilled by a concrete player. Those two specifications form the core of the functional parts of the artifact as a whole and hence they intrinsically exist in the whole all the time. For any artifact, its functional and structural specifications determine the identity conditions, and hence what concrete objects play them is secondary. In other words, as far as it satisfies the two specifications, anything can be the part.

d. A constituent part is an entity which is a selected, yet potential, player for some roles in the given entity A. In role theory this entity is called a constituent role-holder. E.g., an employee of the school (as employee, not the bare person); a component of a car. In short, it is a role-holder which is not actually performing the role. Thus, the constituent part differs from the genuine part because the constituent part is not actually part of the system. Other examples include a teacher sleeping at home or on sick leave, and a car engine removed from the car for maintenance.

A role is played by a constituent role-holder which, in turn, is played by a bare object. In other terms, a bare entity adopted to play one of the roles but not playing it

is a constituent role-holder and it will be a role-holder of a role, when it actually plays that role, thereby becoming a genuine part. This view helps to answer the problem of the parthood relationship between the human rider and the bike. The object riding a bike is not a bare human but a constituent role-holder of the bike, that is, a bare human is not a part of a bike. Instead she, as a constituent role-holder, is a part of the bike while playing a constituent role. When the human playing the constituent role of a bike plays the rider role, she becomes the rider role-holder. These distinctions of parthood subtypes help to make sense of the relationships between a driver and his car while parking to take a rest during a long trip.

## 4. Consequences: School Students and Restaurant Guests

From the functional viewpoint, students are not parts of a school and guests are not parts of a restaurant. They have an "input/output" role rather than functional role. Students are given as "input" to a school which "operates" on them by changing their educational status till the point in which they are "output" at graduation time. Teachers perform teaching and educating functions on students while they work in the school. By analogy, a student for the school is like the water fed to a boiler: the first are transformed in individuals knowledgable in some topics and the latter is transformed in boiling water by the boiler, respectively. A similar argument applies to the customers of a restaurant. Within this view, the oil in a radiator is a part of the radiator and not just an operand because it performs a function (to carry heat energy) in the radiator.

## 5. Concluding Remarks

We have started to integrate the conceptual toolkits provided by parthood and role theory to develop a more expressive parthood approach. For this reason, we reviewed and enriched the analysis of the general parthood relation via notions introduced in role theory, and then briefly revisited a classical parthood examples to see how these are understood and explained within the new approach.

We think this work is preliminary to the study of wholes and to develop a deeper analysis of parthood as used in commonsense and everyday life. We proposed, first, a possible unification of two core ontological theories, namely, role theory and mereology. Second, the identification of four functional parthood notions to help overcome recurrent ambiguities in the standard analysis of parthood examples especially in social and functional contexts. Third, the homogeneous study of different parthood meanings in special cases like, e.g., Guarino's study of car's parts [12]. Fourth, the provision of guidelines and exemplifications about the determination of the parthood relationship among objects in particular in terms of functional parthood.

Even when restricted to the analysis of parthood types, this work is still preliminary under several aspects. In particular, it lacks a study of how this view changes the traditional formalization of mereology (e.g., the extent to which extensionality can be still assumed). In the future we plan to deepen the analysis of the interaction between role theory and mereology considering more parthood notions. Based on these, a study of existing formal theories of mereology will be proposed. Finally, we will investigate

the notion of wholeness that arises from this approach. A topic which inspired us but has not been developed in this paper.

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