1 Introduction

In the quest to create AI systems that can mimic human reasoning capabilities, embedding common sense knowledge (CSK) remains a formidable challenge. This form of CSK, intuitive to humans and foundational to their routine decision-making processes, relies on an understanding of the world based on their interactions. However, for AI systems, mastering this natural grasp of social and physical environments poses a significant challenge. The goal of embedding AI systems with common sense knowledge aims not only to bridge the gap between machine and human interaction and understanding but also to enhance AI systems' ability to perform and interact within the real-world spectrum in a way that is more aligned with human reasoning.

Our work focuses on the manufacturing domain, specifically on the axiomatization of manufacturing common sense knowledge into first-order logic and its conversion into semantic rules using standard vocabulary. We are working to provide AI systems with a foundation based on manufacturing common sense knowledge patterns, to perform reasoning that mimics human reasoning capabilities more closely than ever before. This endeavor highlights the potential of integrating common sense knowledge into the fabric of AI, demonstrating the critical role of structured, logical frameworks in advancing AI's understanding and application of human-like reasoning.

2 Context and Challenges

3 Manufacturing Knowledge

Manufacturing knowledge was defined as knowledge about manufacturing processes, assembly, quality, materials handling, and operation planning by Pahl et al. Manufacturing common sense knowledge refers to a general understanding of basic facts and principles about the manufacturing process that most people know and understand, particularly those who work in or study the field. These basic facts and principles can be considered the 'common sense' of the manufacturing world. There are different types of Patterns in manufacturing regarding common sense as there are four pillars we focus on those pillars to consider these patterns

3.1 Four pillars of manufacturing knowledge

According to Michigan State University[1]

- Materials and manufacturing processes;
- Product, tooling, and assembly engineering;
- Manufacturing systems and operations;
- Manufacturing competitiveness.

[1] https://www.mtu.edu/mmet/graduate/manufacturing-engineering/four-pillars/

3.2 Requirement

"Requirement in Manufacturing Common Sense Knowledge is the understanding that specific tasks or processes in manufacturing require specific tools, equipment, or conditions to be completed successfully. This knowledge is considered 'common sense' because it aligns with the generally accepted understanding that certain tasks necessitate certain prerequisites. It involves recognizing the relationship between a task and its necessary conditions or tools and applying this understanding to predict or plan manufacturing processes."This definition emphasizes the role of common sense in recognizing and applying patterns in manufacturing tasks and their requirements. It's important to note that while this knowledge is often considered 'common sense,' it's also based on specific technical knowledge and experience in the field of manufacturing

3.3 Precedence

Many manufacturing processes must follow a specific order or sequence of steps. This is often called the "process flow" or "workflow." Each step in the process often depends on completing the previous step. This is what you're referring to as "precedence."

3.4 Causation

Causation in manufacturing refers to the cause-and-effect relationships that exist between different steps in a manufacturing process.

3.5 Similarity

many manufacturing processes share similarities due to the nature of the tasks involved.

3.6 Distinctness

the manufacturing processes are distinct due to the materials used, the steps involved, and the products created. Subtypes Can be; Design, Material, and Precedence.

3.7 Part-Hood

Part-hood in manufacturing refers to the components or materials that make up a product or the group or category that a product belongs to. Here are some examples: the product either has certain parts or materials that make it up or belongs to a certain category or group of products. This concept of part-hood is fundamental to understanding how different products are made and how they relate to each other.

3.8 Performance

it's important to note that assessing performance and competitiveness often involves specific knowledge and context that might go beyond 'common' knowledge. It can require detailed information about the particular materials, tools, and processes used, the design's specifics, the market's characteristics, and so on. Some aspects of performance competitiveness can be understood as 'common knowledge.' For example, it's generally understood that using higher-quality materials can improve

Pattern	Example
Material Requirement	A wooden chair requires
Process Requirement	Cutting and assembling are required to man
Tool Requirement	A saw is required to cut
Skill/Capability Requirement	The capability to cut and assemble
Environment/Location Requirement	A workshop is required for cutting and
Process Precedence	Designing the chair comes before cu
Object Precedence in Workflow	The wood must be present before
Existence Precedence	The chair design must exist before the manufa
Material Causation	Using low-quality wood causes the cha
Process Causation	If the assembly process is not properly followed, th
Material Similarity	Both a wooden chair and a wooden
Process Similarity	The cutting and assembling process is similar to a
Tool Similarity	Both processes require the us
Product Characteristic Similarity	Both a chair and a bed can be us
Environment Similarity	Both can be manufactured in a
Material Distinctness	A book is made with paper; a chair is
Process Distinctness	Printing, and binding are required for making a book, while cuttin
Requirement Distinctness	The requirements for making a book (e.g., print format, binding) differ from th
Process Part-hood	Cutting, and joining are parts of the ch
Object Part-hood	A chair consists of parts like legs, a ba
Grouping	A chair can be grouped with other t
Material, Performance	High-quality wood, leads to a s
Process Performance	Effective cutting and joining result in
Product Performance	A well-made chair offers comfor
Environmental Performance	A well-ventilated and safety-compliant workshop leads to
Competitive Performance	A well-made, well-priced chair can outperform

Table 1: Caption

the durability of a product, that a more efficient manufacturing process can lower costs, or that a unique and appealing design can make a product more competitive in the marketplace.

MCSK Patterns

4 Requirement Patterns

4.1 Process Rule Axiom:

To capture the relationship between something being produced and the requirement of a manufacturing process, we'll first have to define or choose the appropriate relations from the ontology (BFO and IOF) that can connect a product (or output) with a process. the relations that are relevant to describe this kind of relationship are:

- **has output**: y has output x if x is an instance of Continuant and y is an instance of Process, such that the presence of x at the end of y is a necessary condition for the completion of y.

- **is output of**: x is output of y if x is an instance of Continuant and y is an instance of Process, such that the presence of x at the end of y is a necessary condition for the completion of y.

Using these relations, let's formulate the axiom:

$$\text{product}(x) \rightarrow \exists y \text{manufacturingprocess}(y) \wedge \text{ is output of (x,y)} \tag{1}$$

Explanation in context of Domain and Range:

- **product(x)**: Specifies that x is a type of product or something that has been produced.
- $\rightarrow$: Represents the implication. It states that if something is a product, then what follows must also be true.
- $\exists y\,[\textbf{process}(y) \wedge x \textbf{ is output of } y]$: For any product x, there exists a process y such that x is the output of the process y.

This axiom captures the idea that for any given product or something produced, there's a process that leads to its creation or production. It essentially formalizes the statement " every product is produced by at least one process".

4.2 Material Requirement Rule Axiom

Every product is dependent on at least one material.

$$\forall p \exists m (\text{Product}(x) \rightarrow \text{bearerof(x, y)} \wedge \text{Material(y)}) \tag{2}$$

Explanation: The axiom represents that for any given entity termed as a product x, there exists another entity, a material m, such that the product x generically depends on this material m at some point in time. The property *bearerof* is used to capture this dependency, as per the property natural language defination a relation between an independent continuant (the bearer) and a specifically dependent continuant (the dependent), in which the dependent specifically depends on the bearer for its existence.

4.3 Machine Requiremnt Axiom:

$$\text{Manufacturingprocess}(x) \rightarrow \exists y \text{machine}(y) \wedge \text{ participatesIn at some time (y,x)} \tag{3}$$

Explanation: This axiom states that for any given process x, there exists a machine y such that y participates in the execution of the process x at some time. This formulation is in line with the domain and range constraints provided. If 'machine' is an instance or subclass of 'independent continuant' (excluding 'spatial region'), then it can participate in a process as per the ontology constraints. **Relation:** *participates in at some time* **Domain Constraints:** The entities that can act as the subject (or starting point) of the relation must be one of the following:

- specifically dependent continuant: Entities that exist by depending on some other entities. For instance, a color (like the redness of an apple) specifically depends on the apple to exist.
- generically dependent continuant: Entities that exist by depending on some entities, but not any particular entity specifically. A classic example might be a type of software; that depends on being installed on some computer to exist but not on any specific computer.

- independent continuant: Entities that exist on their own and are not specifically or generically dependent on other entities. However, they cannot be 'spatial regions'. An example could be a physical object, like a machine.

Range Constraints: The entities that can act as the object (or endpoint) of the relation are: Given the domain constraint: If the term 'machine' falls under 'independent continuant' (and isn't a 'spatial region'), then our axiom from before is consistent with these constraints:

- process: Temporal entities or events that unfold or occur over time. Examples might include manufacturing, baking, or melting.
- Domain: 'specifically dependent continuant' or 'generically dependent continuant' or ('independent continuant' and (not ('spatial region')))

In summary, our axiom states that for any process, there's a machine (that is a suitable type of continuant) that actively engages or takes part in that process at some point in time. This is in line with both the domain and range constraints provided.

Given that the range is "process," the relation *participates in at some time* is suitable to link a machine (as long as it falls within the domain constraints) to a process.

Given the domain constraint: Domain: 'specifically dependent continuant' or 'generically dependent continuant' or ('independent continuant' and (not ('spatial region')))

If the term 'machine' falls under 'independent continuant' (and isn't a 'spatial region'), then our axiom from before is consistent with these constraints.

4.4 Capability Requirement Axiom:

To capture the relationship between a process and the capability required for that process, we need to leverage appropriate relations from the ontology (BFO and IOF). Here, the "has realization" relation is pertinent as it denotes the realization of a capability (or any 'Realizable Entity') in a specific process. The "has realization" property with the domain as Realizable Entity and range as Process makes sense in an ontological context, particularly when using BFO.

In this context:

A Realizable Entity is a type of Dependent Continuant that exists in an entity and manifests in certain conditions or under certain processes. Examples of Realizable Entities include functions, roles, and capabilities.

A Process is an Occurrent that unfolds or occurs over time, and this unfolding or occurring can be seen as the realization of a certain capability, function, or role.

Using the "has realization" property, we can indicate that a certain Realizable Entity (like a capability) is realized or manifested in a particular Process.

In the context of the capability requirement for a manufacturing process, this property allows us to say something like: "A particular capability (Realizable Entity) has realization in a specific manufacturing process."

The relations for this relationship are:

- **has realization**: x has realization y if x is an instance of ‘Realizable Entity‘ (like a capability) and y is an instance of ‘Process‘, such that the manifestation of x is seen in the unfolding or occurrence of y.

Using this relation, the axiom can be formulated as:

$$\text{capability}(x) \rightarrow \exists y \text{process}(y) \wedge \text{ has realization(x,y)} \tag{4}$$

Explanation in context of Domain and Range:

- **capability(x)**: Specifies that x is a type of capability or a ‘Realizable Entity‘.
- $\rightarrow$: Represents the implication, meaning that if something is identified as a capability, then the subsequent statement must also be true.
- $\exists y$ [**process**$(y) \wedge x$ **has realization in** y]: For any capability x, there exists a process y such that x is realized or manifested in the process y.

This axiom illustrates that for any identified capability, there’s a process where this capability is realized. It essentially formalizes the idea: "If a process is unfolding or occurring, a certain capability is realized within that process."

But to capture the relationship between a process and the capability it realizes, we’ll utilize the appropriate relations from the ontology. The relevant relation is:

- **realizes**: If y is a *Process* and x is a *Realizable Entity* (like a capability), then y realizes x means that y is a manifestation or actualization of x.

Using this relation, let’s formulate the axiom:

$$\text{process}(y) \rightarrow \exists x \text{capability}(x) \wedge \text{ realizes (y,x)} \tag{5}$$

Explanation in context of Domain and Range:

- **process(y)**: Specifies that y is a type of process.
- $\rightarrow$: Represents the implication. It states that if something is a process, then what follows must also be true.
- $\exists x$**capability**(x) **realizes(y,x)** : For any process y, there exists a capability x that is realized by the process y.

4.5 Location/Environment Requirement Axiom:

To express the relationship between a process and its required location or environment, we can use the following relation from the ontology:

- **Occurs in** : If y is a *Process* and x is a *Location or Environment*, then y occurs in x at .

Using this relation, let’s formulate the axiom:

$$\text{process}(y) \rightarrow \exists x \text{environment}(x) \text{ occursin(y,x)} \tag{6}$$

Explanation in context of Domain and Range:

- **process(y)**: Specifies that y is a type of process.
- $\rightarrow$: Represents the implication. It states that if something is a process, then what follows must also be true.
- $\exists x$**environment**$(x) \wedge$ **located in at some time(y,x)** : For any process y, there exists an environment x where the process $y$occurs.

To model the idea that certain processes require specific locations or environments, we can utilize properties from your list that relate processes to locations or environments.

the relevant property is:

occurs in This property has the general idea of process occurs in a certain place.

Given the domain and range constraints, we need to ensure that the domain of our property and the range aligns with "Location or Environment". Assuming the domain of the occurs in is Occurent and the range is Independent continuant.

5 Precedence Patterns

5.1 Process Precedence Rule Axiom

Given that there's a process denoted as x, then there must exist another process y that occurs before x. Symbolically, this relationship can be represented as:

$$\text{process}(x) \rightarrow \exists y \text{process}(y) \wedge \text{precedes(x,y)} \tag{7}$$

5.1.1 Explanation:

1. **For any given process** x**:** This is about any process we are considering, which we are naming x.
2. **There exists another process** y **that must occur before** x**:** This means that before the process x can occur, there must be some other process, which we are naming y, that happens first.
3. **This establishes a precedence relationship:** Here, "precedence" means the order in which things should occur. In this context, it means that process y should occur before process x.
4. **process(x):** This denotes x as a process.
5. $\rightarrow$ Again, this represents an implication. In logical terms, an implication (often represented as $\rightarrow$) is a way of saying "if this, then that." In our axiom, it's saying, "if x is a process, then there must be some other process y that precedes it."
6. $\exists y \text{process}(y) \wedge \text{precedes}(x, y)$: This is a formal way of saying there exists a process y such that x precedes y. In other words, y must happen before x.

5.1.2 Precedes domain and range is occurrent:

The term “occurrent” refers to entities or events that happen or unfold over time rather than objects that exist as static, tangible things. In this context, both the domain (the starting point of the relation) and the range (the endpoint of the relation) of “precedes” are occurrents. This means that both the process that is preceding and the one that is being preceded are events or processes that take place over time. === revised===

$$\forall x(\text{process}(x) \wedge \text{partOfSequence}(x) \rightarrow \exists y(\text{process}(y) \wedge \text{precedes}(x, y))) \tag{8}$$

Explanation: This axiom now states that for every process x, if x is part of a sequential chain of processes (denoted by *partOfSequence*(x)), then there exists another process y that follows x. This revised axiom respects the fact that not all processes are part of a sequence, and only those that are part of such a sequence will have a succeeding process.

5.2 Object Precedence Rule

To model the notion that certain objects are prerequisites for a given process, we can utilize the following relations:

- **has input**: A relation where y (a process) has input y (an object) if y is an instance of Continuant that is a necessary condition for the occurrence of process y.
- **is input of**: The inverse of "has input", where y is an input of x if y is a required Continuant for the occurrence of process y.

Formulating the axiom:

$$\text{process}(x) \rightarrow \exists(y)\text{object}(y) \text{ is input of(y,x)} \tag{9}$$

Explanation based on Domain and Range:

- **process(x)**: Specifies that x is a type of process.
- $\rightarrow$: Represents the implication. It states that if something is a process, then what follows must also be true.
- $\exists(y)$**object**(y) **is input of(y,x)** : For any process x, there exists an object y that is a prerequisite for the process x.

Existence Precedence: Given two events or entities x and y, if x precedes y in existence, then the existence or occurrence of y is contingent upon the prior existence or occurrence of x.

- **precedes**: This relationship signifies that one entity or event comes before another in terms of its existence or occurrence.

The axiom can be formulated as:

$$\text{manufacturingprocess}(y) \rightarrow \exists(x)\text{conceptual design}(x) \wedge \text{precedes(x,y)}(x, y) \tag{10}$$

Explanation:

- **manufacturingprocess**(y): This indicates that y represents an instance of manufacturing.
- $\rightarrow$: Represents the implication. It states that if something is an instance of manufacturing, then what follows must also be true.
- **conceptual design**(A): Specifies that x is an instance of conceptual design.
- **precedes**(x,y): The relationship that signifies that the conceptual design x exists or occurs before the manufacturing y.

This axiom captures the idea that for any manufacturing process, there's a prior conceptual design that lays the foundation for the manufacturing process.

6 Casuation Pattern

6.1 Material Casuation Pattern

To express the notion that a specific quality of material directly influences the final product, consider the following relationships:

- **has quality**: Domain is Entity (could be Material Entity) and range is Quality. This represents that an entity, in this case, a material, possesses a particular quality.
- **determines**: This is a hypothetical relationship**need input to define it correctly because it gives more sense than "CAUSE"** that connects the quality of a material to the characteristics of the final product. I suppose the Domain is Quality, and the range is Product (or Continuant, if I think in more general terms) and Quality For example, the carbon content of steel determines its hardness.This means that the quality of a material determines some aspect or attribute of the final product.

The use of "determines" instead of "**causes**" in the context of the relationship between the quality of a material and the final product is deliberate to encapsulate a broader and more nuanced influence. "Causes" typically implies a direct and often linear causal relationship. It suggests a one-to-one correspondence where a change in one entity directly results in a change in another. "Determines," however, allows for a more comprehensive understanding. It encompasses not only direct causation but also the idea that the quality of a material can set conditions or limits within which the final product's attributes fall. For example, the flexibility of a material might not directly cause a product's function but certainly determines the range of functions that the product can effectively perform. Example:

Using "**causes**": The heat resistance of a material causes a cooking pot to be heat resistant. Using "determines": The heat resistance of a material determines the range of temperatures at which a cooking pot can be safely used. o illustrate the nuanced difference between "**causes**" and "determines," and why "determines" is often a more fitting choice for the relationship between the quality of a material and the characteristics of the final product.

In summary, while "causes" implies a direct, straightforward cause-effect relationship, "**determines**" offers a more comprehensive and nuanced understanding. It better fits scenarios in **material science and product design**, where the influence of material properties on the final product is often intricate and multifactorial.

Explanation based on Domain and Range:

- **has quality**: The domain is Material Entity, implying this relation speaks of some material. The range is Quality, which means this material possesses certain qualities or attributes.
- **determines**: I think the domain can be Quality, signifying the properties or attributes of a material. The range being Product(or Continuant,). indicates that this quality has a direct impact or determines some feature of the end product.

Using these relations, the axiom can be framed as:

$$\text{material}(m) \wedge \text{has quality}(q) \rightarrow \exists p \text{product}(p) \text{ determines(q,p)} \tag{11}$$

To convey the concept that a specific quality of material directly impacts the final product, we consider the following relationships:

- **quality**: This relation connects an unspecified domain (which could be inferred as Material Entity given our context) to the Quality it possesses. In our scenario, we will consider the domain as Material Entity.
- **quality of**: This is the inverse of the 'quality' relation. The range of this relation would be Material Entity, and its domain would be Quality.
- **bearer of**: This relation is a sub-property of 'quality'. If a material entity is a bearer of a certain quality, it essentially means that the material possesses or exhibits that quality.

Explanation based on Range, Inverse, and Sub-properties:

- **quality**: Since this relation has no explicitly defined domain, but its range is Quality, it can be applied to any entity to denote that it possesses a particular quality.
- **quality of**: As an inverse of 'quality', this relationship indicates which Material Entity a specific quality pertains to.
- **bearer of**: The 'bearer of' relationship further reinforces the idea that a material entity possesses or exhibits a particular quality.

Using these relations, we can structure the axiom as:

$$\text{material}(m) \rightarrow \exists q \text{quality}(q) \wedge \text{ bearer of(m,q)} \tag{12}$$

This axiom represents the idea that for every material with a specific quality, this quality determines or influences some aspect of the final product.

7 Similarity Pattern

7.1 process Similarity Pattern

Given two processes x and y, they can be considered similar if they share certain inputs, outputs, or other characteristics.

Shared Inputs:

$$\text{Process}(x) \land \text{Process}(y) \rightarrow \text{isSimilarBasedOnInput}(x, y) \leftrightarrow \exists z(\text{hasInput}(x, z) \land \text{hasInput}(y, z)) \tag{13}$$

Shared Outputs:

$$\text{Process}(x) \land \text{Process}(y) \rightarrow \text{isSimilarBasedOnOutput}(x, y) \leftrightarrow \exists z \text{has output}(x, z) \land \text{has output(y,z)} \tag{14}$$

Process-Machine Relationship:

Shared Quality:

$$\text{Process}(x) \land \text{Process}(y) \rightarrow \text{isSimilarBasedOnQuality}(x, y) \leftrightarrow \exists z \text{quality of}(z, x) \land \text{quality of(z,y)} \tag{15}$$

Explanation based on Domain and Range:

- Process (x) and Process(y) declares that (x) and (y) are instances of the "process" class .
- The relations **has input**, **has output**, and **quality of** are used to capture shared characteristics between processes.
- In each equation, the left side (like **isSimilarBasedOnInput**) represents a relationship indicating similarity based on the shared characteristic on the right side.
- The $\leftrightarrow$ symbol represents the biconditional, meaning the two sides are equivalent.
- In each equation, z represents the shared entity, be it input, output, or quality.

7.2 Machine Similarity Axiom:

Two processes x_1 and x_2 are similar if they involve the same machine m:

$$\forall x_1, x_2(\text{process}(x_1) \land \text{process}(x_2) \rightarrow \exists m(\text{machine}(m) \land \text{participatesInAtSomeTime}(\text{m},x_1) \land \text{participatesInAtSomeTime}(\text{m},x_2) \tag{16}$$

Explanation: This axiom states that if there is a machine m that participates in both processes x_1 and x_2 at some point in time, then these two processes are considered similar based on machine similarity . The participation of the same machine in different processes implies a similarity in the processes, possibly in terms of the techniques, operations, or functions performed by the machine. The involvement of the same machine in both processes suggests that they are comparable in certain aspects, such as their operational methods, capabilities, or the type of tasks they perform.

7.3 Material Similarity Axiom:

Two processes x_1 and x_2 are similar if they require the same material m:

$$\forall x_1, x_2 \text{process}(x_1) \land \text{process}(x_2) \rightarrow \exists m \text{material}(m) \land \text{ isinputof}(\text{m},x_1) \ \land \text{ isinputof}(\text{m},x_2) \tag{17}$$

7.4 Location Similarity Axiom:

Two processes x_1 and x_2 are similar if they take place in the same location l:

$$\forall x_1, x_2 \text{process}(x_1) \wedge \text{process}(x_2) \rightarrow \exists l \text{location}(l) \wedge \text{hasparticipantatsometime } (\text{l},x_1) \wedge \text{hasparticipantatsometime}(\text{l},x_2) \tag{18}$$

Explanation: This axiom asserts that if two processes x_1 and x_2 both occur in the same location *loc*, then they are considered similar. The predicate *occursIn* is used to establish the relationship between each process and the location. This reflects the notion that processes occurring in the same physical or conceptual space share similarities, possibly in terms of environmental factors, operational constraints, or contextual relevance.

7.5 Product Quality Similarity Axiom:

Two products p_1 and p_2 are similar if they possess the same quality q:

$$\text{product}(p_1) \wedge \text{product}(p_2) \rightarrow \exists q\,[\text{quality}(q) \wedge (q) \text{ quality of } (p_1) \wedge (q) \text{ quality of } (p_2)] \tag{19}$$

Explanation in context of Domain and Range:

- **product**(p_1 and p_2): Specifies that p_1 and p_2 are types of products or entities that have been produced.
- $\rightarrow$: Represents the implication. It states that if p_1 and p_2 are products, and they possess the same quality, then they are considered similar in this context.
- $\exists q$ [**quality(q)** $\wedge$ **quality of** p_1 $\wedge$ **quality of** p_2]: For any two products p_1 and p_2, there exists a quality q that is a characteristic of both products.

8 Distinctness Axioms

8.1 Process Distinctness:

If two processes x and y have different qualities, then they are distinct.

$$\forall x, y\,(\text{process}(x) \wedge \text{process}(y) \wedge \neg(\text{quality of}(x) \equiv \text{quality of}(y))) \rightarrow x \neq y \tag{20}$$

Explanation:

- quality of(x): Specifies that x (a process) has a certain quality. The domain of the "quality of" property is "Quality" and the range is "Independent Continuant". This means the quality can be identified and attributed to the process x.
- $\equiv$: Represents equivalence between two qualities.
- $\neq$: Represents distinctness between two processes.

$$\forall x, y(\text{process}(x) \wedge \text{process}(y) \wedge \neg\text{sharesQuality}(x, y)) \rightarrow x \neq y \tag{21}$$

his axiom is formulated to establish the distinctness of processes based on their qualities. Let's break down the components for a clearer understanding:

- $\forall x, y$: This denotes that the axiom applies universally to all pairs of entities x and y.
- $\text{process}(x) \wedge \text{process}(y)$: This part of the axiom specifies that both x and y are processes. The axiom is concerned only with entities that are classified as processes.
- $\neg\text{sharesQuality}(x, y)$: Here, $\neg$ represents negation. $\text{sharesQuality}(x, y)$ is a hypothetical predicate function that checks if x and y share any common quality. The negation ($\neg$) thus implies that x and y do not share any common quality.
- $\rightarrow x \neq y$: This is the implication arrow. It indicates that if the conditions specified before it (i.e., both entities are processes and they do not share any quality) are true, then the conclusion after it must also be true. In this case, the conclusion is that x and y are distinct processes ($x \neq y$).

Overall Interpretation:

The axiom essentially states that if two entities are processes and they do not share any common quality, then they are distinct from each other. This is a logical way to categorize processes as distinct, based on the qualities they exhibit or lack. It reflects an understanding that the identity and classification of a process are significantly influenced by its qualities, and differing qualities lead to the classification of processes as distinct entities.

8.2 Material Distinctness:

If two materials a and b have different qualities, then they are distinct.

$$\forall a, b\,(\text{material}(a) \wedge \text{material}(b) \wedge \neg(\text{quality of}(a) \equiv \text{quality of}(b))) \rightarrow a \neq b \tag{22}$$

The structure of the axiom follows First-Order Logic syntax. It uses universal quantification ($\forall$), logical conjunction ($\wedge$), negation ($\neg$), equivalence ($\equiv$), and implication ($\rightarrow$) correctly.

Conceptual Alignment:

- $\text{material}(a) \wedge \text{material}(b)$: This states that both a and b are materials.
- $\neg(\text{quality of}(a) \equiv \text{quality of}(b))$: This implies that the quality of material a is not equivalent to the quality of material b. This part of the axiom assumes that each material has a singular, defining quality, which might be an oversimplification. Materials often have multiple qualities.
- $a \neq b$: This is the conclusion that a and b are distinct materials.

8.3 Requirement Distinctness:

If two requirements p and q have different qualities, then they are distinct.

$$\forall p, q\,(\text{requirement}(p) \wedge \text{requirement}(q) \wedge \neg(\text{quality of}(p) \equiv \text{quality of}(q))) \rightarrow p \neq q \tag{23}$$

Explanation in context of Domain and Range:

- $\rightarrow$: Represents the implication. It states that if two entities (like processes, materials, or requirements) are under consideration and they do not share the same characteristic, they are distinct in terms of that characteristic.
- $\neg\exists c$: Represents the negation of the existence of a characteristic. It suggests that there isn't a characteristic that both entities share.

9 Part Hood Pattern

9.1 Process part hood For the occurrent part

$$\forall x, y(\text{process}(x) \wedge \text{has\_occurrent\_part}(x, y) \rightarrow \text{process}(y)) \tag{24}$$

Explanation: This axiom dictates that for every process x if y has an occurrent part denoted by y, then y is also considered a process.

9.2 process part hood For the temporal part

$$\forall x, y(\text{process}(x) \wedge \text{has\_temporal\_part}(x, y) \rightarrow \text{process}(y)) \tag{25}$$

Explanation: Every process x if comprising a temporal part represented by $y$inherently acknowledges y as a process. This embodies the concept that any temporal phase or fragment of a primary process is, by its nature, a process as well. When we explore the domain and range of the property "hastemporalpart", it's evident that both are labeled as "occurrent". This axiom, therefore, states that if an occurrent entity x has y as its temporal fragment, y should also be categorized as an occurrent entity. Essentially, it encapsulates the notion that any distinct time segment or interval of a primary occurrent entity retains its inherent temporal characteristic.

9.3 Object Part Hood

"Object Part-hood" concept in axioms, based on domain and range:

- Continuant Part of at Some Time: This expresses that a continuant can be a part of another continuant at some specific time instances.

$$\forall x, y(\text{continuantPartOfAtSomeTime}(x, y) \rightarrow (\text{continuant}(x) \wedge \text{continuant}(y))) \tag{26}$$

- Continuant Part of at All Times: This states that a continuant can be a part of another continuant consistently across all time instances.

$$\forall x, y(\text{continuantPartOfAtAllTimes}(x, y) \rightarrow (\text{continuant}(x) \wedge \text{continuant}(y))) \tag{27}$$

- Member Part of at All Times: This represents that a material entity can be a member of another material entity across all time instances.

$$\forall x, y(\text{memberPartOfAtAllTimes}(x, y) \rightarrow (\text{materialEntity}(x) \wedge \text{materialEntity}(y))) \tag{28}$$

- Proper Continuant Part of at All Times: It signifies that a continuant is always a proper part of another continuant.

$$\forall x, y(\text{properContinuantPartOfAtAllTimes}(x, y) \rightarrow (\text{continuant}(x) \wedge \text{continuant}(y))) \quad (29)$$

- Component Part of at All Times: This reflects that a material entity, which is not a fiat object part, is a component of another similar material entity.

$$\forall x, y(\text{componentPartOfAtAllTimes}(x, y) \rightarrow (\text{materialEntity}(x) \wedge \neg\text{fiatObjectPart}(x) \wedge \text{materialEntity}(y) \wedge \neg\text{fiatObjectPart}(y))) \quad (30)$$

- Has Continuant Part at Some Time: It indicates that a continuant can possess another continuant as its part at specific time instances.

$$\forall x, y(\text{hasContinuantPartAtSomeTime}(x, y) \rightarrow (\text{continuant}(x) \wedge \text{continuant}(y))) \quad (31)$$

- Has Continuant Part at All Times: This asserts that a continuant consistently possesses another continuant as its part throughout all time.

$$\forall x, y(\text{hasContinuantPartAtAllTimes}(x, y) \rightarrow (\text{continuant}(x) \wedge \text{continuant}(y))) \quad (32)$$

- Has Member Part at All Times: This indicates that a material entity always has another material entity as its member.

$$\forall x, y(\text{hasMemberPartAtAllTimes}(x, y) \rightarrow (\text{materialEntity}(x) \wedge \text{materialEntity}(y))) \quad (33)$$

- Has Proper Continuant Part at All Times: This conveys that a continuant always has another continuant as its proper part.

$$\forall x, y(\text{hasProperContinuantPartAtAllTimes}(x, y) \rightarrow (\text{continuant}(x) \wedge \text{continuant}(y))) \quad (34)$$

- Has Component Part at All Times: This suggests that a continuant always has another continuant as its component.

$$\forall x, y(\text{hasComponentPartAtAllTimes}(x, y) \rightarrow (\text{continuant}(x) \wedge \text{continuant}(y))) \quad (35)$$

Each axiom is designed based on the domain and range provided for the respective properties. The axiom *"Every object consists of multiple parts"* can be captured using the properties related to *"part-hood"* we've outlined. If by *"object"* we refer to the term *"continuant"*, the property `hasContinuantPartAtSomeTime` or `hasContinuantPartAtAllTimes` is most appropriate for representation. The following first-order logic represents the statement *"Every object (or continuant) consists of multiple parts"*:

$$\forall x(\text{continuant}(x) \rightarrow \exists y, z(y \neq z \wedge \text{hasContinuantPartAtSomeTime}(x, y) \wedge \text{hasContinuantPartAtSomeTime}(x, z))) \quad (36)$$

This axiom asserts that for every continuant x, there exist at least two distinct parts y and z such that y is a part of x and z is a part of x at some time. If one wishes to assert this for all times (not just some), then `hasContinuantPartAtSomeTime` should be replaced with `hasContinuantPartAtAllTimes` in the axiom.

9.4 Grouping

To model the concept of "Grouping" where objects with shared characteristics can be grouped together, we can utilize properties related to characteristics, such as hasQuality and qualityOf. The property hasQuality asserts that a particular object (or continuant) possesses a specific quality or characteristic, and its inverse, qualityOf, denotes the object that has that quality

The notion of *"Grouping objects based on shared characteristics"* can be captured using the properties related to qualities or characteristics.

Given two objects A and B, and a shared quality q, the following first-order logic axiom represents the statement *"Objects with shared characteristics can be grouped together"*:

$$\forall A, B, q(\text{hasQuality(A, q)} \ \wedge \text{hasQuality(B, q)} \rightarrow \text{SameGroup(A, B)}) \tag{37}$$

In this axiom, the predicate SameGroup(A, B) denotes that objects A and B belong to the same group based on shared quality q. If A and B have the same quality q, then they can be grouped together under the SameGroup predicate. It should be noted that the grouping function SameGroup isn't a standard property but serves illustrative purposes here. one might replace SameGroup with an actual mechanism or function to group objects based on their shared qualities.Kindly suggest if any suits the purpose here

10 Performance Patterns

Material Performance

The quality of its material influences the performance of a product. ALmost most of the predicates and a relations are hypothetical as not able to find property based on performance. Kindly suggest any if.

$$\forall p, m, q(\text{madeOf(p, m)} \wedge \text{hasQuality(m, q)} \rightarrow \text{influencesPerformance(q, p)}) \tag{38}$$

Explanation: The predicate 'madeOf' suggests that a product p is constituted or created from material m. The property 'hasQuality' with domain 'independent Continuant' and range 'Quality' implies that the material m possesses a certain quality q. Hence, this quality q affects or influences the performance of the product p.

Process Performance

The quality of a product is influenced by the performance of its processes.

$$\forall p, pr, perf(\text{madeThrough(p, pr)} \wedge \text{hasPerformance(pr, perf)} \rightarrow \text{influencesQuality(perf, p)}) \tag{39}$$

Explanation: The predicate 'madeThrough' indicates that the product p is manufactured or produced through a certain process pr. If this process pr showcases a certain performance measure

$perf$, it will have a direct influence on the quality of product p. The original intention of the axiom was to capture the idea that the performance of the manufacturing process can be a significant factor influencing the quality of the final product. However, as the comment rightly points out, the current formulation presents this as a sufficient condition, implying that the process's performance alone determines the product's quality.

In real-world manufacturing scenarios, product quality is influenced by a myriad of factors, including but not limited to the manufacturing process's performance. Therefore, it's more accurate to consider the process's performance as a contributing factor rather than the sole determinant of product quality.

To address this, the axiom can be reformulated to reflect that the performance of the process is one of the factors that may influence product quality:

$$\forall p, pr, perf(\text{madeThrough(p, pr)} \land \text{hasPerformance(pr, perf)} \rightarrow \text{contributesToQuality(perf, p)}) \tag{40}$$

This revised axiom suggests that the performance of a process pr contributes to, but does not solely determine, the quality of the product p. The predicate *contributesToQuality* is used to denote this more nuanced relationship, acknowledging that while process performance is important, it is one of several factors influencing the final quality of the product.

Product Performance

A well-manufactured product performs its intended function properly.

$$\forall p(\text{wellManufactured}(p) \rightarrow \text{hasFunction}(p)) \tag{41}$$

Explanation: The predicate 'wellManufactured' signifies that a product p is crafted with high standards. The property 'hasFunction' with domain 'independent Continuant' and range 'Function' suggests that this product p is intended to perform a certain function or purpose.

Environmental Performance

The environment plays a role in the product manufacturing efficiency.

$$\forall p, e(\text{exposedToEnvironment(p, e)} \rightarrow \text{influencesEfficiency(e, p)}) \tag{42}$$

Explanation: The predicate 'exposedToEnvironment' conveys that a product p undergoes exposure to an environment e during its production. This environment e can have positive or negative effects on the efficiency with which the product p is manufactured.

Competitive Performance

The market performance of a product is influenced by its quality.

$$\forall p, q(\text{hasQuality(p, q)} \rightarrow \text{influencesMarketPerformance(q, p)}) \tag{43}$$

Explanation: The property ‘hasQuality‘ conveys that a product p possesses a certain quality q. This quality q plays a critical role in determining how well the product p will perform in the market against its competitors.