# Comparing Information Exchange Standard and Basic Formal Ontology Design Patterns

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## Abstract

We outline initial work aligning the Basic Formal Ontology (BFO) and the Information Exchange Standard (IES), illustrating how key design patterns and content structures can be connected across the two frameworks. Our analysis highlights points of ontological convergence and divergence, guided by scenarios and supported by formal modeling. The study contributes to methodologies for mapping between upper-level ontologies and standards-based models while providing insights for communities aiming to improve semantic interoperability.

## Keywords

Basic Formal Ontology, Information Exchange Standard, Ontology Alignment, Competency Questions, Ontology Case Study

## 1. Introduction

Ontologies – controlled vocabularies of terms and logical relationships among them – are a well-known resource for addressing failures of semantic interoperability [1][2]. Ontologies have been leveraged to support data standardization and data integration, machine learning and natural language processing, and automated reasoning [3] in fields such as biology and medicine [4], defense and intelligence [5], industrial manufacturing [6], and proprietary artificial intelligence products [7]. However, development of ontologies by different groups operating in isolation often leads to ontologies whose terms and relations, though designed to cover the same domain, present no obvious, consistent mapping between them. Indeed, where there are apparently obvious mappings, careful analysis often reveals deeper issues. To address such interoperability problems, best practices around ontology engineering have been established, including the adoption of top-level ontologies designed to provide a common starting point for consistent ontology development [8]. Ontologies extending from a common top-level are ideally designed within a single ecosystem, promoting interoperability among members of that ecosystem. Such a strategy does little to address, however, interoperability challenges that arise when one or more ontologies lack a common top-level ontology or when ontologies extend from distinct top-level ontologies. Addressing such challenges seems to require semantic mapping between ontologies [9].

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In rare cases, mapping[1] between ontologies results in equivalencies between asserted classes and relations in one ontology to those in another. More often, the result of mapping between ontologies reveals genuine semantic differences for which simple equivalencies cannot be established among asserted classes and relations. For example, some ontologies allow processes to bear properties, in the interest of reflecting natural language expressions such as ”The plane flight is turbulent” [10]. Ontologies that characterize change as the gain or loss of properties and so insist that processes do not change because they are changes, typically do not permit processes to bear properties [11]. This is not the space to arbitrate such choices; it is sufficient to note this example highlights a genuine semantic difference between ontologies.

Such differences are often obscure to those working outside specific ontology engineering circles. Steps have been taken among foundational ontology developers to lay bare genuine semantic differences [12]. In what follows, we seek to take further steps down this path by comparing two distinct ontologies having overlapping scope, but differing semantics: the Information Exchange Standard (IES4) and the Basic Formal Ontology (BFO). IES4 is an ontology used for data exchange; it is actively being used across UK Ministry of Defence (MOD) components and partner organizations in the defense, law enforcement, national and transport security, and intelligence communities [13]. IES4 is also being used by the UK's National Digital Twin Programme and parts of the Australian defence sector. BFO is an ISO 21838-2 designated [8] top-level ontology designed to support interoperability across all domains of scientific investigation, with a significant presence in biomedical, industrial manufacturing, and defense and intelligence, across academia, government, and commercial sectors. As a top-level ontology, BFO consists of highly general classes - such as **material entity**[2] and **process** - and relations - such as **continuant part of** and **participates in**. Among its over 700 extensions is the Common Core Ontologies (CCO), a widely-used suite of eleven ontologies representing entities at a level more specific than BFO, yet more general than domain-level ontologies, with classes such as **agent** and **artifact**, as well as relations such as **is about** [14]. As we will see, many classes in IES are also more specific than what is in the scope of BFO itself, and are rather closer in their level of generality to what is in CCO.

There is considerable overlap across these efforts and it is thus worth investigating the extent to which their respective semantics converge and diverge. We aim in this article to outline initial efforts to map between these ontologies, focused on common scenarios.

## 2. Information Exchange Standard (IES)

### 2.1. User Community

IES4 is designed to support a broad range of communities engaged in high-assurance data integration, semantic interoperability, and tracking of how things change over time. IES4 has been developed with cross-domain applicability in mind, facilitating its current use across defence, law enforcement, national security, transport and national infrastructure. Its emphasis on unified temporal and spatial fidelity makes it especially well-suited for complex systems where entities change over time and need to be tracked across phases and contexts [15].

### 2.2. Ontological Commitments of IES

IES4 is grounded in extensionalism, leading to super-substantivalism and four-dimensionalism plus other commitments that are shared with the BORO methodology [16]. The thesis of super-substantivalism is that spacetime and its material occupants are identical [17]. Four-dimensionalism is on the other hand the thesis according to which all entities are to be understood as having spatial-temporal extent. According to four-dimensionalism, it is not just processes and events that are to be treated as having

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[1] An ontology mapping, or correspondence, is a statement <*s*, *p*, *o*> such that *s* is a subject term representing a class or object property in a ontology, *o* is an object term representing a class or object property in some other ontology, and *p* is a predicate that specifies how *s* and *o* relate.

[2] We adopt the convention of displaying classes and relations in bold.

temporal parts, but also entities that are in common sense understood as being 3-dimensional, such as persons and tables. This approach allows us to directly say things about temporal states of entities. The approach goes further though – extent is the criterion for identity – if two things occupy the same spacetime, they are the same thing. Contrariwise, things which occupy distinct spacetime regions, for instance Trump in his first and second terms, are not identical. This foundation allows IES4 to represent how things change over time, making it particularly effective for representing the movement or changing characteristics of things, including the changes in parts of things, which becomes more and more useful the higher the complexity of the represented system [13].

## 2.3. Core Classes and Relations

**Table** 1 shows representative core entities modeled in IES4. These include classes and properties derived from IES4 to enable structured information exchange with high semantic clarity. The standard is also accompanied by sample data files and usage examples, allowing users to validate, test, and demonstrate alignment with the ontology [15].

Table 1 presents some of the highest-level classes found in IES4. The standard is also accompanied by sample data files and usage examples, to help users validate, test, and demonstrate alignment with the ontology [15].

**Table 1**
Core Classes and Relations in the Information Exchange Standard v4 (IES4)

| IES4 Class/Relation | Description |
|---|---|
| **Thing** | A rdfs:Resource which is a real or possible world ‘thing’. |
| **Entity** | Typically represents a tangible thing like a Person, a Communications Device, or a Location. |
| **Representation** | A ClassOfEntity whose instances are representations of things in the real world. |
| **Element** | A Thing that has a spatial extent and can have start and end dates. |
| **State** | A temporal state of an Element. |
| **PeriodOfTime** | An Element whose spatial extent is everywhere, but whose temporal extent is limited. |
| **EventParticipant** | A State which is the participating role in an Event. |
| **ClassOfElement** | An rdfs:Class and a Thing whose instances are classes of Element. |
| **Event** | An Event represents an activity or incident, involving one or more participating entities, that occurred/started at a specific point in time, e.g. a meeting, or a telephone call. |
| **Attribute** | A feature or property of a Thing. |
| **Relationship** | A relationship represents an association between two Things. |
| **isPartOf** | Relationship linking an Element to another that it is part of. |
| **isStateOf** | An isPartOf relationship linking an Element to a temporal State of that Element. |
| **isParticipationOf** | An isStateOf that relates an EventParticipant to the Element that is the participant. |
| **isParticipantIn** | An isPartOf that relates an EventParticipant to the Event it participates in. |

Instances of **Element** in IES are spatio-temporal extents which can have start and end dates, these include entities (for example, person), as well as states and events (for example, meeting). Instances of **Entity** (**Entity** is a subclass of **Element**) are typically used to represent tangible material objects such as a person, device or facility. **ClassOfElement** is the powerset [18]of **Element**. IES4, like BORO, has an unbounded approach to the number of class levels permissible, allowing for additional powersets to be added at any level [18].

Each member (instance) of the class **Entity** in IES4 is a spatiotemporal extent extending from its creation (or birth) to its destruction (or death). In order to model the changes an entity undergoes over its lifespan, **States** are used to refer to their temporal parts. These states can be instantiated based on the properties which an entity possesses for a given timespan e.g. its location and/or characteristics. This may also include timespans where the entity participates in **Events**. Moreover, IES4 distinguishes between things in the real world and our representations of them, specifying that a **Representation** is not a physical thing. A person's name would be an example of **Representation**, however names are only one type of representation. In IES4, representations also include documents, videos, images etc.

Entities participate in Events using a special type of **State** called an **EventParticipant**. The class **Event** is used to capture temporally bounded occurrences and activities involving one or more states of **Entity** instances that occurred during a specific timespan. Formally, the spatiotemporal extent of an **Event** is the fusion or mereological sum of all **States** that participate in the event.

In a BORO ontology like IES4, mereology is key to describing not only the composition of things but also where they are located in spacetime. A fundamental relation is used to do this which is **isPartOf**. When we refer to temporal parts of things we use a subtype of **isPartOf**, called **isStateOf**. Referring to the time a thing happened is treated much the same as referring to where it is in space – using mereology between spacetime extents. **inPeriod** is a special type of **isPartOf** relation that links a 4D extent to a **PeriodOfTime**. A **PeriodOfTime** is a temporal part of the universe and provides the 4D mechanism to talk about the temporal nature of things e.g. when they started and when they ended. Applying mereology to describe locations within spacetime offers a significant advantage: it inherently accommodates representing incomplete or less detailed information about times. When you have imprecise information about when or where something occurred – for example, knowing an event happened 'on the 1st of January 2020' without specifying a precise time – mereology provides a consistent framework to model this imprecision. Instead of requiring a separate mechanism for vague or imprecise information, the same parthood patterns are used i.e. – we have a **inPeriod** to the period of time of '1st of January 2020'. If we later learn that this thing, more precisely, happened at 10am on that day, then we also have the **inPeriod** relation to "10am on 1st of January 2020". The same would apply to specifications of spatial information e.g. locating a person in a country, versus a region of that country. The approach is additive – new knowledge does not impact the semantics of the old.

Overall, IES4's foundations as a 4D ontology provides reusable patterns that support talk of both spatial and temporal aspects of entities - including how they change over time and the level of epistemological precision with which they are known.

## 3. Basic Formal Ontology (BFO)

### 3.1. User Community

Basic Formal Ontology (BFO) is a top-level ontology designed to support information integration, retrieval, and analysis across all domains of where empirical data is deployed, including scientific investigation, government administration, industry, and defense and security. [1][8]. Containing only general terms common across disciplines, BFO serves as the top-level ontology of the Open Biological and Biomedical Ontology (OBO) Foundry [19], the Industrial Ontology Foundry (IOF) [20] and the National Security Ontology Foundry (NSOF) [14]. BFO provides a foundation for over 700 open-source ontology extensions across diverse domains such as infectious disease[21], plant development [22], industrial maintenance [23] and many others [24].[3] It is the first top-level ontology designated as an ISO standard, and is publicly available in Web Ontology Language (OWL) and Common Logic Interchange Format (CLIF) implementations.[4]

### 3.2. Ontological Commitments of BFO

BFO adopts the following commitments:

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[3] http://basic-formal-ontology.org/users.html

[4] https://github.com/BFO-ontology/BFO-2020

- **Ontological Realism:** BFO and its extensions are designed to represent reality itself, not merely concepts or linguistic conventions or spatiotemporal extents [1].
- **Fallibilism:** Scientific understanding is provisional and may be updated as knowledge advances [20].
- **Adequatism:** Every scientific discipline merits representation in its own terms, not merely via reduction to one or more other disciplines [25].

### 3.3. Core Classes and Relations

Table 2 provides definitions and elucidations within the BFO hierarchy. The ISO 21838-2 standard documentation includes conformance criteria to help users validate, test, and demonstrate alignment with BFO [8].

Terms in BFO and in BFO-conformant ontologies represent classes of instances that share important features. The highest division in BFO's class taxonomy is between **occurrent** and **continuant**. **Occurrents** are extended in time in such a way as to have temporal parts, where **continuants** lack temporal parts and endure through time. **Continuants** and **occurrents** are tied together by the fact that the former participate in the latter, as when a child participates in an act of crying or a mother participates in an act of consoling. There are three subclasses of **continuant**. An **independent continuant** is a **continuant** that does not depend on anything for its existence [1]. A landmass is an **independent continuant**, its mass and shape, on the other hand, depend for their existence on it and are accordingly categorized in BFO as **specifically dependent continuants**, instances of which in every case depend for their existence on some entity.

**Independent continuant** has two sub-classes: **material entity** and **immaterial entity**, the former having and the latter lacking material parts. Subclasses of **material entity** include: **objects**, such as Beyoncé, **object aggregates**, such as Destiny's Child, and **fiat object parts**, such as the left hemisphere of Beyoncé's brain. **Object aggregates** consist of disjoint unions of **objects**, where **objects** consist of **material entities** that are maximal with respect to some causal unity criterion, such as the unity exhibited by surface boundaries, by forces between fundamental particles, or by fastening through engineering processes (for example, via welding). **Fiat object parts** belong to a family of proper parts of **objects** that are demarcated by fiat, such as your head, or Mount Everest, or the Southern Hemisphere of the Earth.

The **material entity** class is closed under BFO's **continuant part of** relation, so that any entity that has a **material entity** part is itself a **material entity**. Subclasses of BFO's **immaterial entity** class include spatial regions and **sites** (such as your mouth ora hole in the ground on a golf course), as well as various **continuant boundary entities** (for example the boundary separating the interior and exterior of a golf course). By providing such clearly defined, high-level, class distinctions, BFO helps users avoid common modeling mistakes, such as conflating the material constituting a river and a site through which the material flows.

Certain instances of **specifically dependent continuant** are fully manifested whenever they manifest at all, such as color, shape, or mass; these are instances of the BFO class **quality**. **Realizable entities**, in contrast are those **specifically dependent continuants** which are marked by the fact that they may exist without manifesting. For example, a flotation device can float in water, even when it is not being deployed. Two major subclasses of **realizable entity** recognized by BFO are **dispositions** and **roles**. **Dispositions** are **realizable entities** that are internally grounded, which means for a **disposition** to begin or cease to exist, its bearer must undergo some physical change. For example, a portion of salt may lose its solubility, but only if it undergoes some change to its physical structure [25].

**Role** is a disjoint sibling class of **disposition** whose instances are optional, in the sense that bearers may gain or lose them without thereby exhibiting any physical change. They are in this sense said to be externally grounded. A student who graduates from a university no longer bears the **role** of student at that institution, but that need not entail any change to the physical structure of the student. This feature allows **roles** to be borne by entities that do not have material parts, such as the boundaries of a country, the location where a river used to be, or the internal cavity of a bear's mouth. **Dispositions**

| BFO Class | Elucidation/Definition |
|---|---|
| **continuant** | An entity that persists, endures, or continues to exist through time while maintaining its identity. |
| **independent continuant** | A continuant which is such that there is no $x$ such that it specifically depends on $x$ and no $y$ such that it generically depends on $y$. |
| **specifically dependent continuant** | A continuant which is such that (i) there is some independent continuant $x$ that is not a spatial region, and which (ii) specifically depends on $x$. |
| **generically dependent continuant** | An entity that exists in virtue of the fact that there is at least one of what may be multiple copies. |
| **material entity** | An independent continuant that at all times at which it exists has some portion of matter as continuant part. |
| **object** | A material entity which manifests causal unity and is of a type instances of which are maximal relative to the sort of causal unity manifested. |
| **object aggregate** | A material entity consisting exactly of a plurality (≥1) of objects as member parts which together form a unit. |
| **quality** | A specifically dependent continuant that, in contrast to roles and dispositions, does not require any further process in order to be realized. |
| **realizable entity** | A specifically dependent continuant that inheres in some independent continuant which is not a spatial region and is of a type some instances of which are realized in processes of a correlated type. |
| **role** | A realizable entity that exists because there is some single bearer that is in some special physical, social, or institutional set of circumstances in which this bearer does not have to be, and is not such that, if it ceases to exist, then the physical make-up of the bearer is thereby changed. |
| **disposition** | A realizable entity such that if it ceases to exist, then its bearer is physically changed, and its realization occurs when and because this bearer is in some special physical circumstances, and this realization occurs in virtue of the bearer's physical make-up. |
| **function** | A disposition that exists in virtue of the bearer's physical make-up and this physical make-up is something the bearer possesses because it came into being, either through evolution (in the case of natural biological entities) or through intentional design (in the case of artefacts), in order to realize processes of a certain sort. |
| **occurrent** | An entity that unfolds itself in time or is the start or end of such an entity or is a temporal or spatiotemporal region. |
| **process** | An occurrent that has some temporal proper part and for some time has a material entity as participant. |
| **spatiotemporal region** | A spatiotemporal region is an occurrent that is an occurrent part of spacetime. |
| **temporal region** | A temporal region is an occurrent over which processes can unfold. |
| **spatial region** | A spatial region is a continuant entity that is a continuant part of the spatial projection of a portion of spacetime at a given time. |
| $x$ **generically depends on** $y$ | $x$ is a generically dependent continuant & $y$ is an independent continuant that is not a spatial region & at some time $t$ there inheres in $y$ a specifically dependent continuant which concretizes $x$ at $t$. |
| $x$ **continuant part of** $y$ | $x$ and $y$ are continuants & there is some time $t$ such that $x$ and $y$ exist at $t$ & $x$ continuant part of $y$ at $t$. |
| $x$ **occurrent part of** $y$ | A relation between occurrents $x$ and $y$ when $x$ is part of $y$. |
| $x$ **participates in** $y$ | Participates in holds between some $x$ that is either a specifically dependent continuant or generically dependent continuant or independent continuant that is not a spatial region & some process $y$ such that $x$ participates in $y$ some way. |
| $x$ **concretizes** $y$ | $x$ is a process or a specifically dependent continuant & $y$ is a generically dependent continuant & there is some time $t$ such that $y$ is the pattern or content which $x$ shares at $t$ with actual or potential copies. |
| $x$ **inheres in** $y$ | $x$ is a specifically dependent continuant & $y$ is an independent continuant that is not a spatial region & $x$ specifically depends on $y$. |
| $x$ **temporally projects onto** $y$ | holds between a spatiotemporal region $x$ and some temporal region $y$ which is the temporal extent of $x$. |
| $x$ **spatially projects onto** $y$ | holds between some spatiotemporal region $x$ and spatial region $y$ such that at some time $t$, $y$ is the spatial extent of $x$ at $t$. |
| $x$ **occupies spatiotemporal region** $y$ | holds between a process or process boundary $x$ and the spatiotemporal region $y$ which is its spatiotemporal extent. |

are not afforded such a status, given their dependence on the material structure of bearers. The class **disposition** has a single subclass in BFO, namely **function**, which is a **disposition** that reflects the reason for the existence of its bearer, such as the heart's **function** to pump blood or the **function** of a knife to cut. In each case, the reason the bearer exists is because it has the **function** it bears. The class **function** itself has many subclasses recognized in domain-specific ontologies, for instance the protein functions recognized in the Gene Ontology, or the functions of data structures recognized in the Information Artifact Ontology.

**Generically dependent continuant** is a sibling class of **independent continuant** and **specifically**

**dependent continuant**. A **generically dependent continuant** is in the simplest sort of case a copyable pattern. A pattern exists only if it is concretized in some bearer but it is not dependent on any specific bearer, because it may be copied (for example through being transmitted) from one bearer to another. Examples of **generically dependent continuant** include coordinate systems, coding paradigms, the content of novels, paintings, poems, and so on.

In the BFO **occurrent** hierarchy, subclasses cover temporal and spatiotemporal regions, processes, and boundaries of processes. Instances of **process** have temporal parts and must have at some point a **material entity** which **participates in** them. For example, baking a cake is a **process** involving material ingredients. **History** is a subclass of **process** reflecting the totality of all **processes** in which a given **material entity** participates. It is assumed that each **material entity** has exactly one **history**. Poor John may lose his hand one evening, at which point the **history** of John and the **history** of John's hand diverge. BFO **processes** have **process boundaries**, such as their beginnings and endings, instances of which would fall under the BFO class **process boundary**. Both **processes** and **process boundaries** will exist over some **temporal region**, the former over a **temporal interval** while the latter at a **temporal instant**. BFO's **participates in** relation bridges **continuants** and **processes**, more generally, both of which are related to **spatiotemporal regions**, which project on the **spatial regions** in which the relevant **continuant** is located and the **temporal region** over which the relevant **process** occurs.

### 3.4. General Comparison

Before turning to direct comparisons of BFO and IES4 representations, it is worth comparing ontological commitments.

BFO restricts its domain to actual entities. Nonetheless, BFO can be extended where necessary, for instance, to represent classes of entities that do not yet exist, such as car models still in the design phase or molecules that have not yet been synthesized. In general, however, membership in a BFO class implies an entity actually exists. In contrast, the domain of IES4 includes also merely possible entities. Examples include the hypothetical meteor that could have wiped out life on Earth in 2012, or a scenario in which you, the reader, were jogging instead of reading this paper. Moreover, IES4 does not draw a distinction between actual and possible entities. For example, an event that is not occurring would not be recognized as merely possible based on class membership alone. Similarly, an actual event would not be explicitly labeled as occurring in the actual world. However, ad-hoc subclasses, as illustrated in the diagram, can be introduced to enable a more explicit mapping.

Another notable difference is that because IES4 fundamentally represents everything in terms of spatiotemporal regions [16], graphs based on IES4 will often be less complex than graphs based on BFO, for a given domain. As we see below, BFO representations can be viewed as expansions of IES4 representations, and IES4 representations as contractions of BFO representations.

## 4. Comparison through Scenarios

Following the aforementioned ontology mapping research leveraging translation definitions [26], IES4 and BFO teams are developing parallel graphs that represent the same scenario or use case, in order to compare the two ontological structures. This work effectively lays the foundations for the construction of axiomatic translation definitions between these structures. To that end, we here compare semantic convergence and divergence by introducing a handful of scenarios taken from the domain of policing and investigation. This work is best understood as highlighting plausible semantic equivalence; future work will explore the construction of axiomatic translation definitions to prove semantic equivalence.

### 4.1. Representing a Physical Entity

Figure 1 displays how two graphs in IES4 and BFO may represent the same phenomenon, and so be in some sense semantically equivalent. To illustrate in IES4, suppose john-doe$_{IES4}$ is an instance of the IES class **Entity**. Ontologically, this means that he is the 4-dimensional space-time extent corresponding to the whole life of John Doe. To aid with the mapping to BFO, in this graph we furthermore added “De Se Actual Material Entity”, a term that represents IES4 entities that exist in the actual world and that have some material entity as part. While IES4 generally does not distinguish between entities that exist in a different possible world than ours and those that do, we added this specific distinction to conceptually facilitate the mapping to BFO.

To illustrate in BFO, suppose john-doe$_{BFO}$ is an instance of BFO **object**. john-doe$_{BFO}$ occupies a succession of **spatial regions** over the course of his **history**. The relevant instance of BFO **history**, history$_{john-doe}$, consists of all the **processes** which occur in the **spatiotemporal region** occupied by john-doe$_{BFO}$ through his life. This spatiotemporal-region$_1$ instance **spatially projects onto** the aforementioned succession of **spatial regions**, which we represent by the instance spatial-region$_1$, and **temporally projects onto** the **temporal region** that is the duration of his life, which we represent with the instance temporal-region$_1$.

Bridging IES4 and BFO, we maintain that history$_{john-doe}$ has the same temporal extent as john-doe$_{IES4}$. Our example suggests an equivalence between john-doe$_{IES4}$ on the one hand and on the other, john-doe$_{BFO}$, history$_{johndoe}$, and its corresponding spatiotemporal-region$_1$, spatial-region$_1$, and temporal-region$_1$.

This simple example highlights that establishing semantic equivalence between IES4 and BFO must involve not only underlying metaphysical and definitional commitments, but also the establishment of graph-to-graph or structural equivalences in terms of classes, relations, and instances. In this example, IES4 provides a more compact graph representing the scenario, packing information into a single node that one sees expanded in the BFO graph representation. Ideally, with semantic equivalences established between these structures, users will be able to automate the transformation of representations from, say, a more expansive BFO graph representation into a more compact IES4 representation, and vice versa.

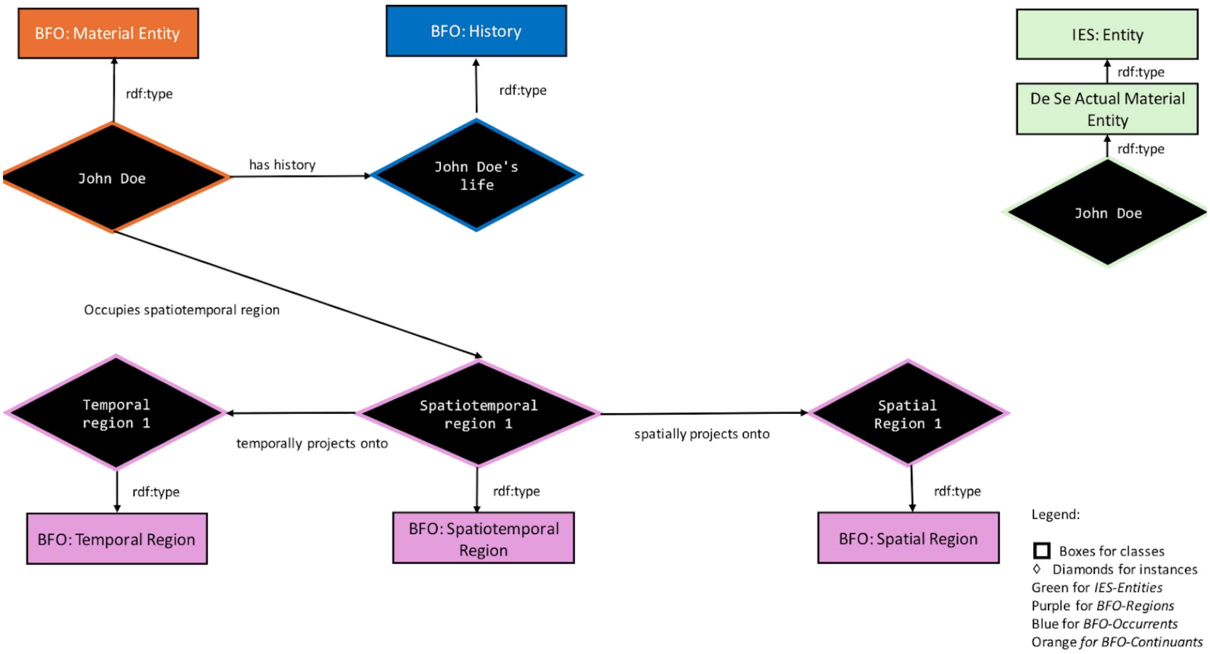

**Figure 1:** John Doe modeled in IES4 (left) and in BFO (right)

This dual design pattern applies to all 4-dimensional entities in IES4 that, from the commonsensical perspective, have some material entity at their core. This observation allows us to generate more such equivalence graphs representing high-level patterns in IES4 and BFO. The design patterns we introduce in subsequent sections provide further equivalence graphs based on more nuanced scenarios.

## 4.2. Police Scenario 1: Investigators and Suspects

Our next scenario presents a situation that relevant to domains like security, defense and surveillance, and adds more details compared to representing a single person:

> A single subject of interest - Harry - is being investigated by a single investigator working on the operation - Bindi. A Senior Responsible Officer - Sam - leads Operation Badger, which involves investigating the criminal organization RAIDERS.

IES4 models the example in this fashion: all the persons involved are extents in space-time, and their job occupations or roles in the investigation are all IES **Person States**, so smaller 4-dimensional extents compared to their respective persons. Bindi has after all not been an investigator from birth to her death, but just for a portion of her life, and so for the others. The relation between nodes corresponding to Bindi and those corresponding to investigator$_1$ is **isParticipationOf**, which is a sub-property of **isStateOf** used to connect a smaller spatiotemporal extent to a bigger one. Investigator$_1$ is moreover related to the collective action of investigating, i.e. investigation$_1$ by **isParticipantIn**. The temporal boundaries of these states are determined by the length of the involvement of the suspects in the police operation, that is, from the time when they became targets of the operation to the time when they ceased to be investigated. Repeating this pattern for all persons in the scenario, we can see the result in Figure 2:

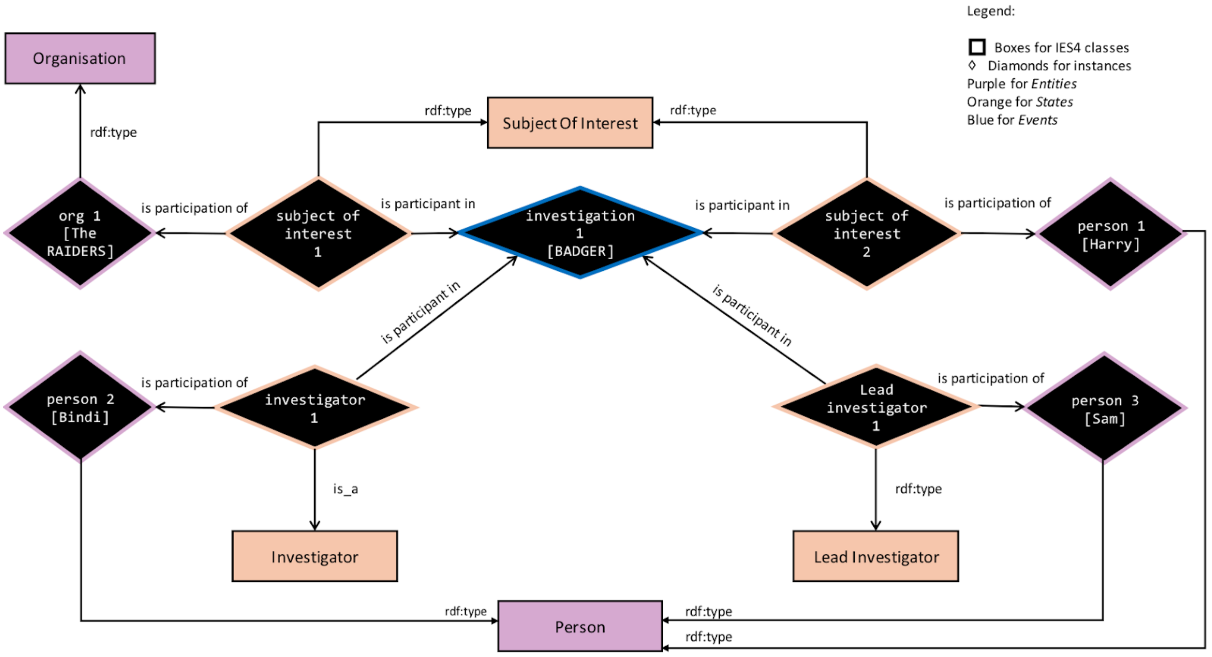

**Figure 2:** Police Scenario 1 in IES4

IES4 includes relevant subtypes of **Entity** such as **Person** and **Organisation**, useful for expressing how people and organizations are involved in Operation BADGER investigations. This is accomplished by having a **State** for each **Entity** involved in the operation, whether they are being investigated or conducting the investigation. Temporal boundaries of said **States** are determined by the length of the involvement of the suspects i.e. when they became targets of the operation to the time when they ceased to be investigated. The same holds for the investigators, who are considered investigators from the point at which they began participating in the investigation in such a capacity.

Turning now to BFO, there is a central **process**, namely the investigation$_1$, which delimits all other relevant **processes**. Recall, BFO's classes and relations are highly general, and so do not include, for example, classes for persons or organizations. It is at this point useful to leverage a widely-used extension of BFO to more closely match the IES4 representation of Police Scenario 1. To that end, we introduce here useful classes from the Common Core Ontologies (CCO), in particular the classes **organization** - a subclass of BFO's **object aggregate** - and **person** - a subclass of BFO's **object**. RAIDERS is an instance of the former, while Bindi, Sam, and Harry are each instances of **person**. Building on the previous BFO design pattern, Bindi, Sam, and Harry are connected to respective instances of **history** and the **spatiotemporal region** which that **history** occupies. As we are focusing largely on occupations and a process of investigation, investigation$_1$, we omit representing all these histories and spatio-temporal regions, which would otherwise be included in a full BFO graph. Each **person** in this scenario bears some **role**. Bindi bears investigator$_1$, Sam lead-investigator$_1$, and Harry subject-of-interest$_1$. As discussed above, **roles** existentially depend on their bearers, so were Bindi to go out of existence, so too would her role as investigator$_1$. As **realizable entities**, **roles** may bring about further **processes**, such as when the lead-investigator$_1$ **role** manifests by directing a team or writing reports.

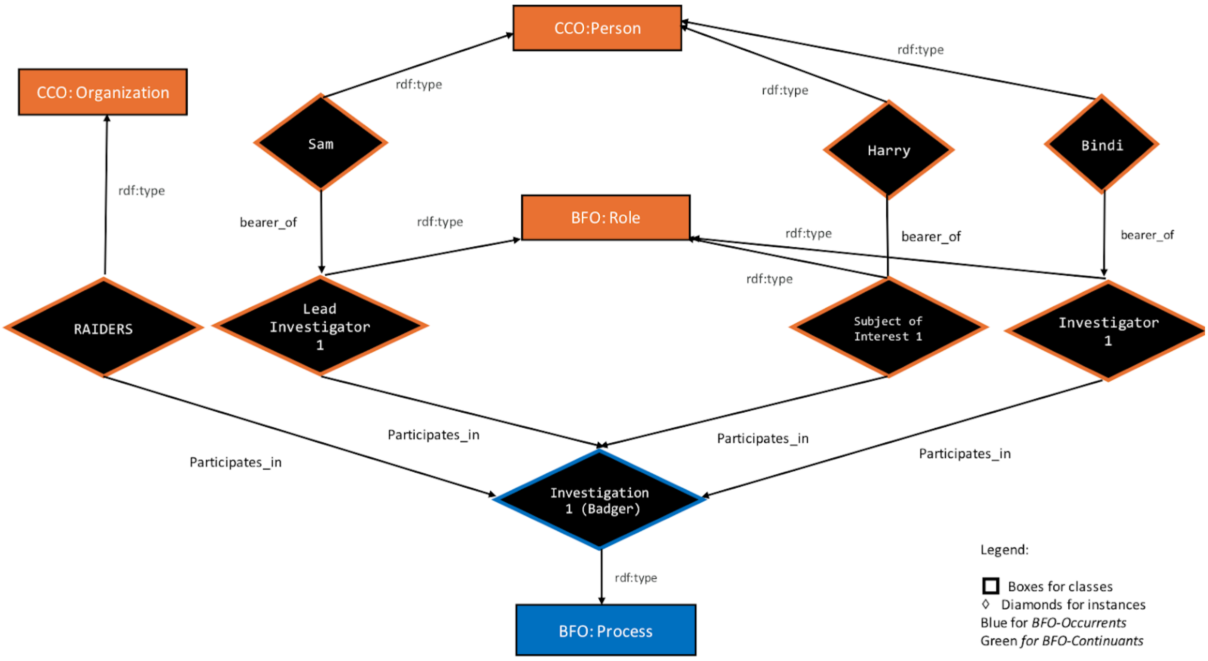

**Figure 3:** Police Scenario 1 in BFO

These graphs and our discussion suggests several semantic connections between IES4 and BFO with respect to this scenario, namely, by interpreting the BFO **continuant** representations in IES4 spatio-temporal terms.

### 4.3. Police Scenario 2: Naming and Investigating

In our final scenario, we incorporate additional information about the people and organizations involved in the investigation. In any police operation, having accurate information is crucial for identifying and distinguishing entities. Initially, investigators might possess only scattered or uncertain intelligence regarding a crime, along with the knowledge that it was committed by an organized group. This group could be familiar to the police, in which case much is already known, or it could be a completely new organization, with its size and objectives yet to be determined. In either case, investigators can assign a provisional name to the unidentified criminal organization and then work to associate it with, or distinguish it from, known groups. To highlight this a realistic scenario, we model the following scenario: Operation BADGER is investigating an Organised Crime Group called the RAIDERS.

Figure 4 shows a part of investigation BADGER as seen from the IES4 perspective, where the

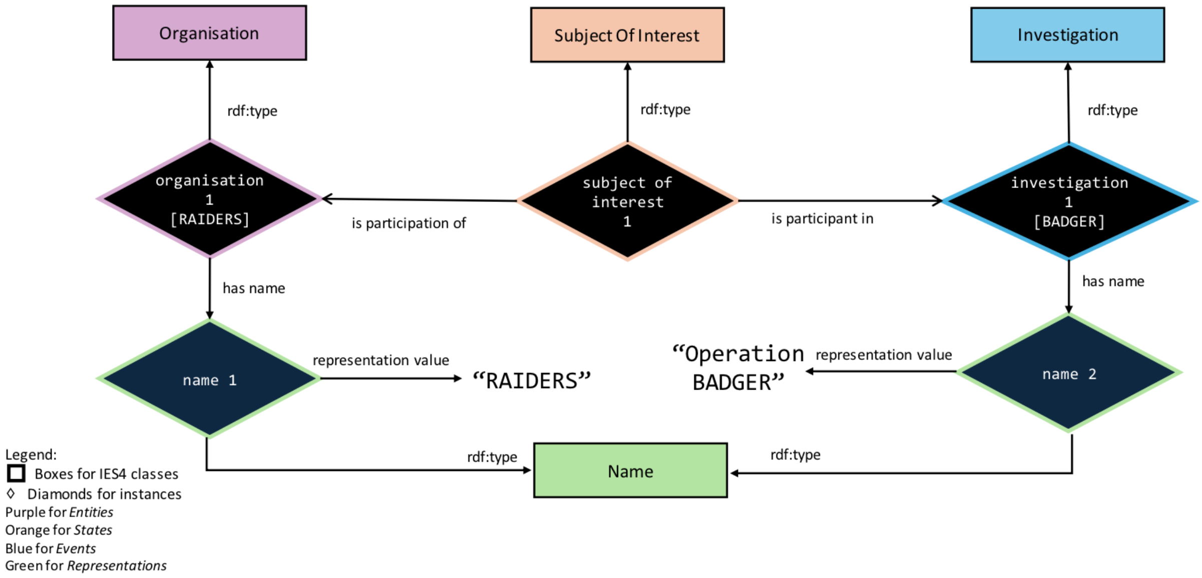

**Figure 4:** Police Scenario 2 in IES4

**organisation** RAIDERS is involved as the **subject of interest**. If we want to include the names of the organisation ("RAIDERS") and the investigation ("Operation BADGER"), we create separate entities to represent them, as IES rigorously distinguishes between things and their representation. String values are then attached to the representing names, and not to the represented entities. We then create instances of type **Name** for both the **organisation** (name 1) and the **investigation** (name 2). Each **Name** instance then has a representation value which is the actual string used as the name.

Turning now to BFO, Figure 5 illustrates organization$_1$ **participates in** investigation$_1$, which is an instance of the CCO class **planned act**. The unfolding of investigation$_1$ is, moreover, prescribed by operation-Badger-plan$_1$, which is a CCO **information content entity**, that is, a **generically dependent continuant** that is about something in the world. Additionally, operation-Badger-plan$_1$ is said to **generically depend on** in this case a CCO **information bearing entity**, which is simply a **material entity** on which there is generic dependence, such as a physical document detailing the operation.

As an instance of **organization**, organization$_1$ is an aggregate of individuals who intend to **participate in** coordinated activities. This instance bears a CCO **designative name** instance name$_1$, which **generically depends on** document$_2$ which has text value "RAIDERS". Though not displayed in Figure 5, investigation$_1$ is also designated by a name which **generically depends on** document$_1$ which has the text value "Operation BADGER". Put another way, operation-badger-plan$_1$ both prescribes and names the investigation.

## 5. Discussion

Our initial comparison of IES4 and BFO demonstrates both the feasibility and the strategic value of mapping between independently developed ontological frameworks. The results show that while these systems arise from different philosophical and design commitments - IES4 from a four-dimensionalist, extensionalist perspective emphasizing temporal and spatial fidelity, and BFO from an ontological realist perspective emphasizing formal clarity and modular extensibility - practical alignment is an achievable goal. In multiple scenarios, including the representation of persons, organizations, roles, and investigative processes, we were able to develop high-level mapping patterns that preserve semantic intent while revealing structural correspondences.

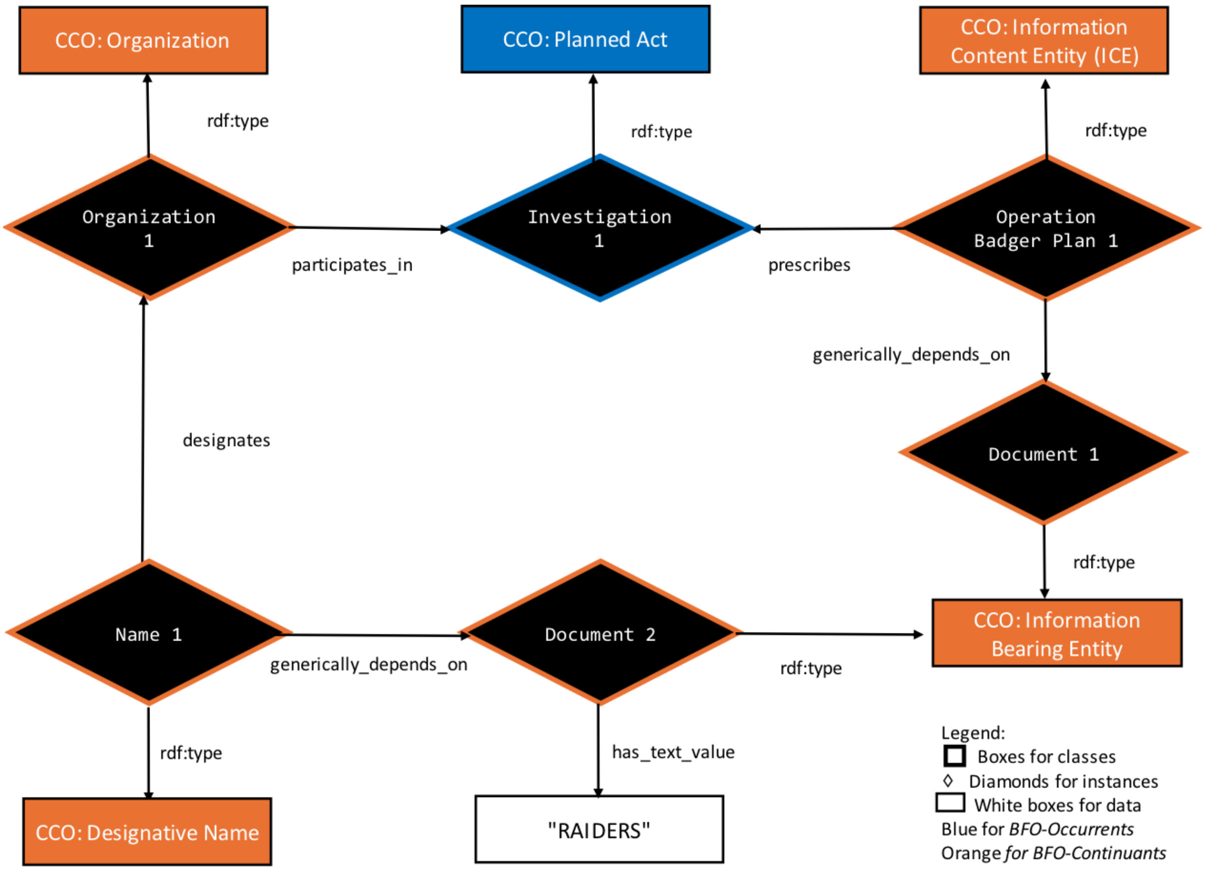

**Figure 5:** Police Scenario 2 in BFO

A key benefit of this work is that it has facilitated cross-community interoperability without forcing premature convergence on a single metaphysical stance. By explicitly identifying where the ontologies align and where they diverge, we lay the foundations for bidirectional transformation of data and for automated reasoning across systems that adopt either standard. For practitioners in defense, security, and intelligence domains, where both frameworks are already in operational use, this alignment will reduce translation overhead, mitigate information loss, and support more integrated analytics. More broadly, the initial mapping examples we provided here offer a reusable methodological template for reconciling other top-level or domain ontologies with divergent ontological commitments, and indicate how to operate to produce other mappings.

These preliminary results also point toward concrete opportunities for future work. Our present mapping is limited to a focused set of entity types and scenarios. Expanding this to cover qualities or attributes, various dependent continuants, process boundaries, and higher-order class structures will be essential for full-spectrum interoperability. Looking ahead, moreover, the construction of axiomatic translation definitions will allow us to move from plausible semantic equivalence to provable equivalence.

At the same time, several foreseeable challenges must be acknowledged. First, the fundamental difference between IES4's treatment of all entities as spatiotemporal extents and BFO's distinction between **continuants** and **occurrents** means that certain mappings will inevitably involve information expansion or contraction. In some cases, transformations may require introducing auxiliary entities or relations, increasing graph complexity. Second, while our results support confidence that mappings between IES4 and BFO can be obtained, it is an open question whether there will be in every case correspondence between them. For example, differences in the treatment of possible versus actual entities may make the construction of axiomatic translation definitions challenging, if not impossible. Third, while the use of bridging patterns enables high-level interoperability, ensuring consistent interpretation across user communities will require documentation, training, and potentially governance mechanisms to guide adoption.

Overall, this work demonstrates that careful, pattern-based mapping between IES4 and BFO is both achievable and beneficial, but it is not a “set-and-forget” exercise. The path forward involves deepening the coverage of mappings, formalizing translation rules, and embedding the resulting interoperability framework into real-world systems. By sustaining collaborative engagement between the IES4 and BFO communities, we can both advance semantic integration in these domains and develop transferrable methods applicable to other ontology alignment challenges.

## 6. Conclusion

The long-standing promise of ontologies has been to improve the clarity, precision, and interoperability of complex data systems. However, realizing this promise requires more than publishing well-structured models, it requires ontologists to engage across organizational and conceptual boundaries. This paper offers a concrete example of how such work might proceed—by suggesting how to map two semantically rich but historically siloed frameworks, we highlight both the benefits and the complexities of ontological alignment.

The future of applied ontology will depend on projects like this one, projects that are not only technically rigorous, but also require collaboration across ontology engineering efforts. As standards proliferate and domains evolve, the ontology engineering community must cultivate shared practices and shared understanding. We encourage researchers, practitioners, and standards developers alike to invest in the hard but necessary work of semantic integration. If we can work and learn together - across sectors, systems, and paradigms - we stand a better chance of making good on the promise that has animated ontology from the beginning: shared meaning at scale.

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## Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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