Complex Systems Informatics and Modeling Quarterly
CSIMQ, Article 54, Issue 11, June/July, 2017, Pages 20–37
Published online by RTU Press, https://csimq-journals.rtu.lv
https://doi.org/10.7250/csimq.2017-11.02
ISSN: 2255-9922 online

The OntoREA Accounting Model: Ontology-based Modeling of the Accounting Domain

Christian Fischer-Pauzenberger [1*] and Walter S.A. Schwaiger [1*]

[1] Institute of Management Science, Technische Universität Wien,
Theresianumg. 27, 1040 Wien, Austria

christian.fischer-pauzenberger@tuwien.ac.at, walter.schwaiger@tuwien.ac.at

Abstract. McCarthy developed a framework for modeling the economic rationale of different business transactions along the enterprise value chain described in his seminal article "The REA Accounting Model – A Generalized Framework for Accounting Systems in a Shared Data Environment" Originally, the REA accounting model was specified in the entity-relationship (ER) language. Later on other languages – especially in form of generic data models and UML class models (UML language) – were used. Recently, the OntoUML language was developed by Guizzardi and used by Gailly et al. for a metaphysical reengineering of the REA enterprise ontology. Although the REA accounting model originally addressed the accounting domain, it most successfuly is applied as a reference framework for the conceptual modeling of enterprise systems. The primary research objective of this article is to anchor the REA-based models more deeply in the accounting domain. In order to achieve this objective, essential primitives of the REA model are identified and conceptualized in the OntoUML language within the Asset Liability Equity (ALE) context of the traditional ALE accounting domain.
Keywords: REA accounting model, ALE accounting model, OntoUML, OntoREA accounting model.

1 Introduction

McCarthy [1] introduced the REA accounting model to conceptualize the economic logic of accounting in terms of economic resources (R) that are exchanged in economic events (E) between economic agents (A). In contrast to conventional accounting literature he looked at the accounting theory from a stock and flow perspective with the REA accounting framework. This framework, called the REA accounting model, was developed using data modeling techniques, and its underlying structure is found to consist of sets representing economic resources, economic events, and economic agents plus relationships among those sets. [1, p. 554]. The economic core of the REA accounting model is the duality principle. The duality relationship expresses the economic rationale that scarce resources have a positive price that has to be paid in

---

* Corresponding author

© 2017 Christian Fischer-Pauzenberger and Walter S.A. Schwaiger. This is an open access article licensed under the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0).

Reference: Ch. Fischer-Pauzenberger and W.S.A. Schwaiger, "The OntoREA Accounting Model: Ontology-based Modeling of the Accounting," Complex Systems Informatics and Modeling Quarterly, CSIMQ, Issue no. 11, pp. 20–37, 2017. Available: https://doi.org/10.7250/csimq.2017-11.02

an exchange transaction from the buyer to the seller. McCarthy relates economic resources closely to tangible assets. He explicitly distinguishes economic claims from the economic resources to emphasize the temporal imbalance between the flows of the economic resources in business transactions like, e.g. credit card sales and sales on account.

The REA accounting model was extended by Geerts and McCarthy [2], [3] to the REA business ontology by including a policy infrastructure next to the accounting infrastructure. This conceptualization extends the economic logic by a forward looking and a typification perspective so that business policies can be considered for the acquisition, conversion, revenue as well as financing and investment transactions. The term ontology refers to Gruber’s definition [4] of an ontology as a specification of a conceptualization. This definition is mainly used in the knowledge representation and management domain. It clearly distinguishes from the metaphysical understanding of ontology. Such an understanding is applied, e.g. by Wand and Weber [5] in information systems research where they use Bunge’s metaphysical ontology concept in order to ground information systems upon an ontological foundation.

A more recent development is Guizzardi’s Unified Foundational Ontology (UFO) [6]. UFO is built on the metaphysical foundation of the four-category ontology by Lowe [7] and therefore distinguishes at the highest level between Universals and Individuals. Universals are space-time independent classifiers that define patterns of features. Individuals, on the other hand, are particular things that instantiate specific Universals in space and time. Furthermore, UFO relies on a hierarchical object type structure [8] which gets further specialized by incorporating meta-properties along the way from the origin to the leaves. Meta-properties are ontological notions drawn from philosophy like the principle of essence and rigidity, identity, unity and dependency. These principles have their origins in Formal Ontology which is incorporated in OntoClean [9] as a further ontological source of UFO. Finally, the part of UFO (UFO-A) which deals with the meta-properties of the types of entity and relationship is supported with the OntoUML language [6], [10]. OntoUML is an UML extension that incorporates the ontological meta-properties and makes them accessible in ULM class diagrams via stereotypes. OntoUML can be considered as a modernized entity-relationship (ER) language by covering ontologically differentiated types of entities and types of relationships.

Gailly et al. [11] are the first ones who use the OntoUML language in order to classify the primitives in the REA enterprise domain ontology (REA-EO) in terms of the metaphysical UFO upper-level ontology. They model the REA primitives represented in the form of economic resource, economic event and economic agent in UFO terms as Role, Relator and Role Mixin, and duality is considered as Formal relation. This classification of the REA primitives has shown to be beneficial for their research focus related to REA’s enterprise domain ontology. But for the applicability of this classification in the accounting domain the question arises: Does this classification also adequately cover all essential elements of the accounting domain?

In the article question will be answered in a negative way because of two reasons: Firstly, in the ALE accounting context it is important to identify the provider of the identity principle and not just the carriers of an identity principle. The identity providers have to be rigid so that they can always be traced back unanimously over time. This holds for economic resources, economic events and economic agents as well. Consequently, e.g. the typification of an REA-EO Economic Resource as an UFO Anti-rigid Sortal Universal is not adequate. Secondly, in the Asset Liability Equity (ALE) accounting domain the duality relationship constitutes a material and not just a formal relationship. The materiality comes from the contracting that underlies each business transaction. This contracting mediates between the economic agents in an economic event. Furthermore the contracting contains a value constraint between the opposite flows of economic resources in the dual economic events. The incorporation of the value constraint will be called Balanced Duality Relationship.

The argumentation for the deeper anchoring of the REA models into the ALE accounting domain will be provided in two steps.

In the first step a refined representation of the REA-based accounting domain is constructed. This representation is a refined version of Schwaiger's [12] REA-based ALE accounting model. The refinement relates to the inclusion of the balanced duality relationship which integrates the value constraint into the duality relationship. Furthermore the claims are explicitly delineated from receivables and payables, from contractual financial instruments and from the owner's equity. By following this distinction, claims are only related to imbalances in the debit and credit events arising from misaligned event realizations (e.g. sending or receiving resources before invoicing or without transfer of control).

In the second step the refined REA-based ALE accounting model is translated from the UML language into the OntoUML language. In this translation the additional vocabulary of the OntoUML language provides the ontological meaning in form of existence, identity, temporality and modality to the different classes. Equipped with this additional information the derived OntoREA accounting model conceptualizes a framework designed to be used for different purposes. One possibility is its usage in the accounting (AIS – see Romney et al. [13]) as well as enterprise information systems (EIS – see Dunn et al. [14]) research by establishing ontology-based accounting and enterprise information systems. Such systems could be designed and implemented, e.g. within a model-driven software development approach (see, e.g. Brambilla et al. [15], Stahl and Völter [16] or Pergl et al. [17]) by establishing the OntoREA-based conceptual model first and subsequently transforming it into a software application.

The article is organized along the reification of different variants of the duality relationship. In the subsequent section the duality relationship is reified as a separate UML class model. The reason for this reification lies in an enhanced understandability of this essential concept in the REA accounting model. This is helpful for capturing the extensions in the next section where the REA-based ALE accounting model is based upon the balanced duality relationship which is defined and reified again as a separate UML class model. Afterwards the refined REA-based ALE accounting model is translated into the OntoUML language by directly integrating the balanced duality relationship and by specifying all cardinalities as well as OntoUML stereotypes. In the final section the conclusions of the article are provided.

2 REA Accounting Model: Reification of the Duality Relationship

The REA accounting model (Figure 1) conceptualizes a generalized accounting framework designed to be used in a shared data environment where both accountants and non-accountants are interested in maintaining information about the same set of phenomena. This framework is developed using data modeling techniques, and its underlying structure is found to consist of sets representing economic resources, economic events, and economic agents plus relationships among those sets. Correspondence of REA elements with the accounting theories is discussed in [1]. The practical use of the model in the database design phases of view modeling and view integration is presented, and some REA representations of accounting objects are reconciled with those representations found in conventional double-entry systems. [1, p. 554].

McCarthy [1, pp. 562–563] uses the following definitions of economic resource, economic event, economic agent and duality as well as claims [1, p. 568]:

- *Economic resources are defined ... to be objects that (1) are scarce and have utility and (2) are under the control of an enterprise. In practice, the definition of this entity set can be considered equivalent to ... the term "asset" ... with one exception: economic resources in the schema do not automatically include claims such as accounts-receivable.*
- *Economic events are ... "a class of phenomena which reflect changes in scarce means [economic resources] resulting from production, exchange, consumption, and distribution."*
- *Duality relationships link each increment in the resource set of the enterprise with a corresponding decrement .... Increments and decrements must be members of two different*

event entity sets: one characterized by transferring in (purchase and cash receipts) and the other characterized by transferring out (sales and cash disbursements).

- *Economic agents include persons and agencies who participate in the economic events of the enterprise or who are responsible for subordinates' participation. Agents in this sense can be considered equivalent to ... "entities." That is, they are identifiable parties with discretionary power to use or dispose economic resources.*
- *Claims, or future assets ... derive from imbalances in duality relationships where an enterprise has either: (1) gained control of a resource and is now accountable for a future decrement (future negative asset) or (2) relinquished control of a resource and is now entitled to a future increment (future positive asset).*

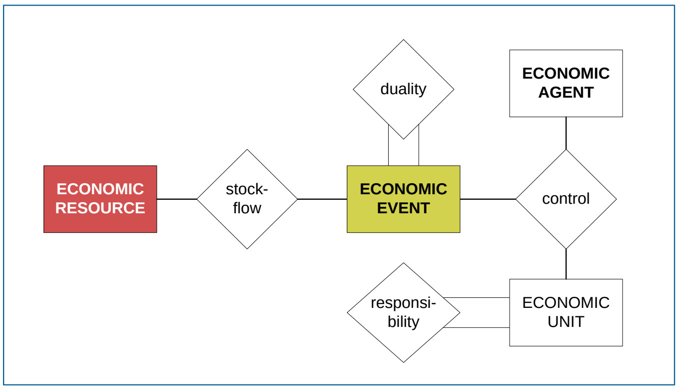

Figure 1. REA Accounting model [1, p. 564] – ER language

Figure 2 shows the REA accounting model in the UML language which is used in the ISO/IEC 15944-4:2007 standard related to the Accounting and Economic Ontology (AEO) to model business transactions [18, p. 16] and by Schwaiger and Abmayer [12], [19], [20] for the REA-based accounting domain modeling. The REA accounting model is focusing on the resource flows that occur in economic transactions between the involved agents. The duality relationship expresses the economic principle that scarce resources have a positive price that has to be paid in an exchange transaction. The inclusion of the business location information in the REA accounting model is due to its intention that both accountants and non-accountants are interested in maintaining information. As the focus in this article is the accounting domain, this information will not be addressed any further.

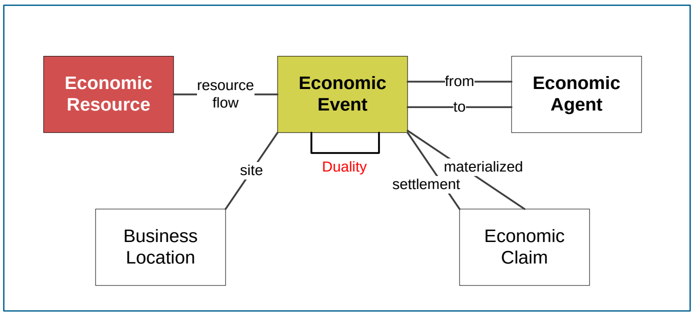

Figure 2. REA Accounting model [12] – UML language

The figure contains the duality relationship named *Duality*. The capitalized naming intends to indicate a reification of that relationship, which is introduced in order to enhance the understandability of this important concept. To keep the REA accounting model close to its original version the reification is shown outside the model within a separate diagram.

For illustration purposes the duality relationship is demonstrated within a simple example in Figure 3. In the cash purchase transaction the enterprise buys from the supplier a commodity and pays for it in cash. In this case the duality relationship connects one increment event (on the left hand side) with one decrement event (on the right hand side). The arrows indicate the resource flow from one agent (from agent) to another agent (to agent). Concerning the agents the two involved resources flow into the opposite directions. At the top of Figure 3 the Duality relationship is shown as a rectangle. It connects the increment event on the left with the decrement event on the right hand side.

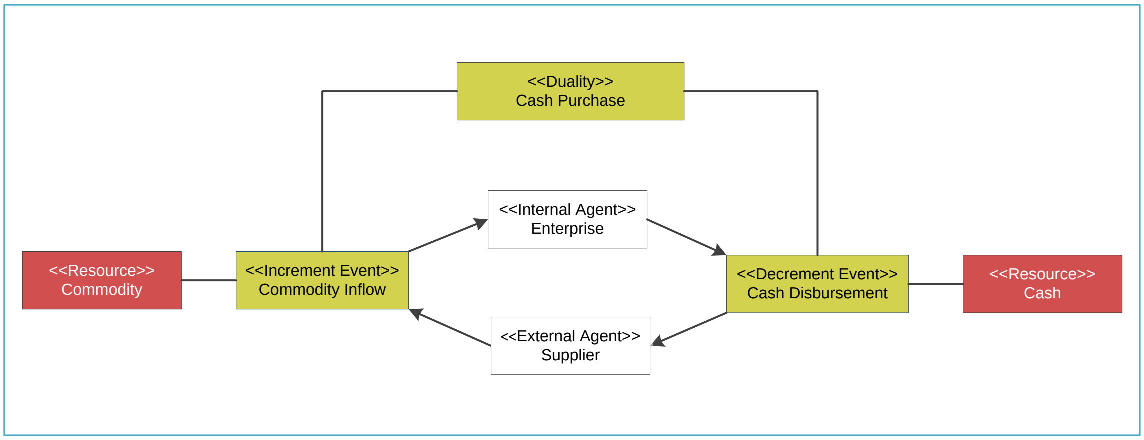

Figure 3. Duality relationship – cash purchase transaction

The reification model for the generic duality relationship in the UML language can be seen in Figure 4. The duality relationship is reified via the Duality relationship class located in the middle of the diagram. The Duality class is linked to the Increment Event class and to the Decrement Event class. According to the cardinalities, one increment (decrement) event is connected to one business transaction. On the other hand, one business transaction is connected to one or many increment (decrement) events. Furthermore, one or many resource flows are connected to one increment (decrement) event; and one resource flow is linked to one increment (decrement) event. Finally two agents are involved in the business transaction, i.e. the *from* agent who delivers and the *to* agent who receives. Depending on the nature of the business transaction different internal and/or external agents are involved. In the cash purchase transaction, e.g. the enterprise is an internal agent that receives the commodity from the supplier who is an external agent.

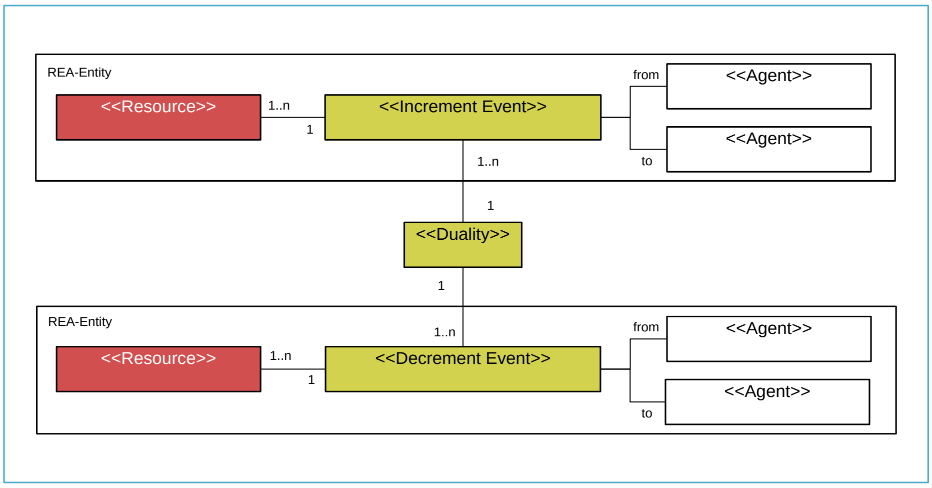

Figure 4. Reified Duality relationship – UML language

3 REA-based ALE Accounting Model: Reification of the Balanced Duality Relationship

Although the original REA accounting model is intended to specify the accounting domain it does not cover several important accounting requirements. The following are the main deficiencies of the REA accounting model with respect to the traditional Asset Liability Equity-/ALE-accounting logic [21]:

1. The narrow focus on (tangible) assets is not compatible with the more comprehensive asset, liability and equity view of ALE accounting.
2. The duality relationship establishes matches between increment and decrement events but it does not cover the value constraint associated with the business transactions' debit and credit events, i.e. the balanced duality relationship.
3. The focus on resource flows is not sufficient to cover the recording requirements of changes in the resource values (e.g. depreciations).
4. The broad definition of claims neglects the delineation to the claims related assets and liabilities (e.g. receivables, payables and financial instruments) as well as equity resources.

In order to eliminate these shortcomings the REA-based ALE accounting model developed by Schwaiger [12] is considered. To promote understandability, in this article, the argumentation underlying this model is summarized as follows: The conventional reasoning in accounting starts with the accounting equation, which specifies the resources of the enterprise as assets and the claims to those resources as liabilities and equity. The assets are owned and the liabilities are owed by the enterprise. The equity is the owner's claim to the net value of the enterprise which is defined as the difference of the assets and the liabilities. *The account category (asset, liability, equity) governs how we record increases and decreases. For any given account, increases are recorded on one side, and decreases are recorded on the opposite side. The following T-accounts provide a summary*:

Assets		Liabilities and Owner's Equity	
Increase = Debit	Decrease = Credit	Decrease = Debit	Increase = Credit

These are the rules of debit and credit. Whether an account is increased or decreased by a debit or a credit depends on the type of account. Debits are not "good" or "bad". Neither are credits. Debits are not always increases or always decreases – neither are credits. [21, p. 92].

In conventional accounting stocks and flows of assets (A), liabilities (L) and equity (E) are considered. Consequently the ALE-based accounting includes more resource types than the REA accounting model. Next to the tangible resources it also contains financial resources and categorizes these into financial asset, liabilities and equity.

Once assets, liabilities and equity are considered, the increment and decrement events have to be aligned with the double-entry recording by using the debit and credit notations. The increment and decrement notations used in the REA accounting model are not sufficient to cover all business transactions. E.g. a balance sheet extension transaction in form of a debit financing increases the cash resource and the liability resource at the same time. The double increase is not possible in the REA accounting model but it is possible according to the ALE category properties. By using the debit and credit concepts this problem gets solved. The increment of the cash is credited and the increment of the liability is debited.

The problem with the broad definition of economic claims is solved by narrowing the claim definition. In the ALE context, different types of claims can be categorized as follows:

- Claims from the enterprise vis-à-vis its debtors – as assets (e.g. receivables).
- Claims from the creditors vis-à-vis the enterprise – as liabilities (e.g. payables and loans).

- Claims from the owner vis-à-vis the enterprise – as owner's equity.

The narrowed claim definition relates to those temporal imbalances in the duality relationship, which are not any of the three aforementioned claim types. Examples of such claims would be a delivery of goods without invoicing or transferring control rights. Such claims are not yet recorded in the double-entry bookkeeping system although resource flows already occurred. Their inclusion into the REA-based ALE accounting model provides a good example why such a model conceptualizes a generalized accounting framework. As in the REA-based ALE accounting model all accounting requirements are fulfilled, the model actually conceptualizes a generalized full-accounting framework, which clearly distinguishes from the generalized (partial-) accounting framework related to the REA accounting model.

The REA-based ALE accounting model, which remedies all four deficiencies, is shown in Figure 5. Its distinguishing features are as follows:

- It covers all resources related to the assets, liabilities and equity instead of the primary focus on physical assets and cash in the REA accounting model.
- It includes the business transaction class, which is missing in the REA accounting model. This element is the conceptual starting point of accounting professionals and academics. Its inclusion anchors the ontology in the accounting domain. Furthermore the business transaction class contains the value constraint requirement related to debit events and credit events, which is also missing in the REA accounting model.
- It uses the value flow relationship related to debit and credit events instead of the stock flow relationship related to increment and decrement events in the REA accounting model. The reason for this modification lies in the fact that not only resource flows have to be accounted for in the ALE accounting model. In actual accounting the periodic income also includes profits and losses that result, e.g. from changing resource prices. Such value changes occur without resource flows. On the other hand, all resource flows are related to value flows so that in the value flow relationship all accounting relevant events are captured.
- It has a correctly specified claims class, which only contains the temporal imbalances in the duality relationship that are not claims that underlie certain asset, liability and equity positions from the balance sheet.

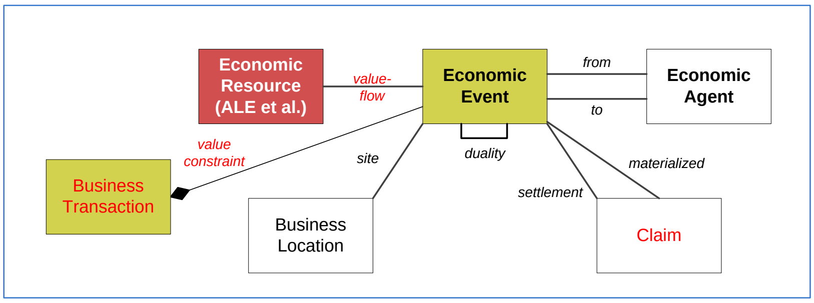

Figure 5. REA-based ALE Accounting model [12] – UML language

The REA-based ALE accounting model can conceptually be refined by integrating the business transaction concept that contains the value constraint into the duality relationship. The combined concept is termed *balanced duality relationship*. This relationship is capitalized in Figure 6 to indicate its reification in a separate diagram.

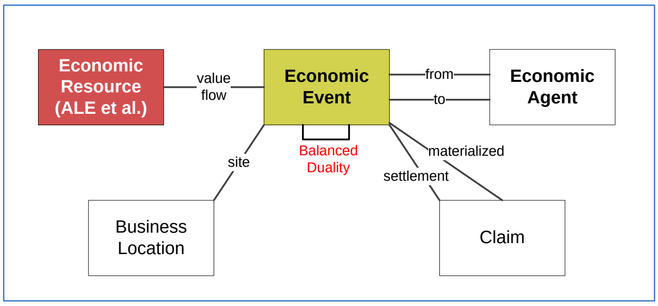

Figure 6. REA-based ALE Accounting model (refined) – UML language

For illustration purposes also the balanced duality relationship is demonstrated first within a simple example (Figure 7). In an acquisition transaction the resource that flows into the enterprise is the commodity. The outflowing resource is cash. The inflowing resource is connected to the debit event *Commodity Inflow*, which increases the stock of the commodity resource in the enterprise. The outflowing cash resource is linked to the debit event *Cash Disbursement*, which decreases the enterprise's stock of the cash resource.

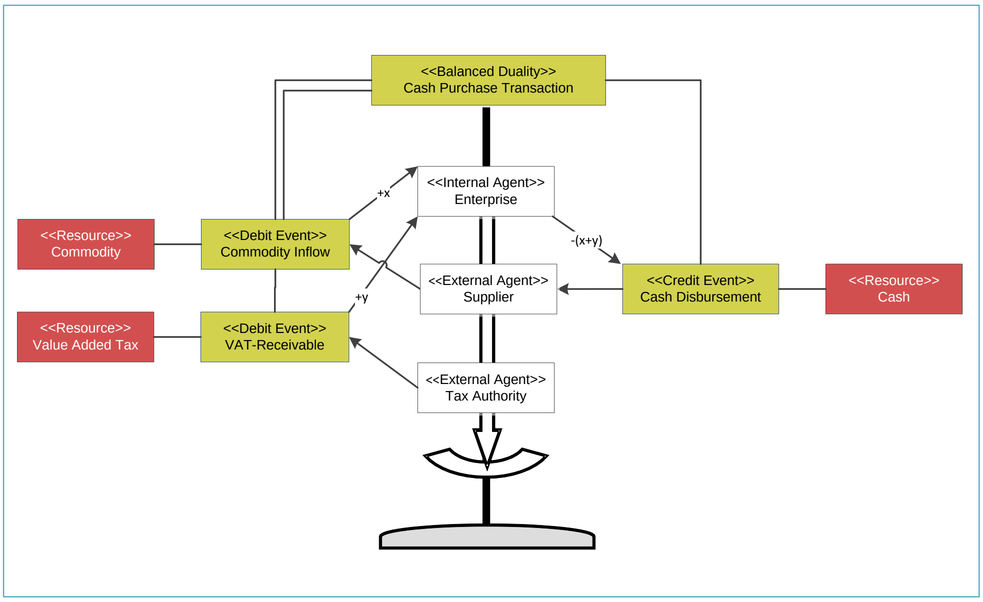

Figure 7. Balanced Duality relationship – cash purchase transaction

Furthermore, the tax consideration is incorporated in the example. This can be seen by the second debit event, which is related to the value added tax (VAT). The VAT is included in the invoice amount and it is therefore paid in cash by the enterprise. It is a receivable against the tax authority that can be deducted by the enterprise from the VAT payables stemming from the enterprise's revenue businesses with its customers.

At the top of Figure 7 the Balanced Duality relationship is shown as a rectangle. It connects two debit events on the left with one credit event on the right hand side. The value constraint within the balanced duality relationship can be seen by the variables x and y in the diagram. These currency unit amounts (x, y) indicated on the three resource flows show that the absolute value of the two debit events is equal to the absolute amount of the credit event. This is the value constraint requirement, which has to hold in each business transaction. The "+" sign indicates an inflow and the "–" sign signals an outflow. Next to the mathematical expression the value constraint can be seen in iconic form by the position of the arrow in the middle of the figure. It is positioned straight down so that both sides of the scale have the same (monetary) weights. The reification model for the generic balanced duality relationship in the UML language can be seen in Figure 8. The balanced duality relationship is reified via the Balanced Duality relationship class located in the middle of the diagram. The Balanced Duality class links to the Debit Event class and to the Credit Event class. All the cardinalities are the same as in the reified duality relationship model. The major distinction to this model is, firstly, the usage of the debit/credit event typification instead of the increment/decrement typification and, secondly, the inclusion of the value constraint that requires that the value of all debit events in the business transaction is the same as the value of all of its credit events.

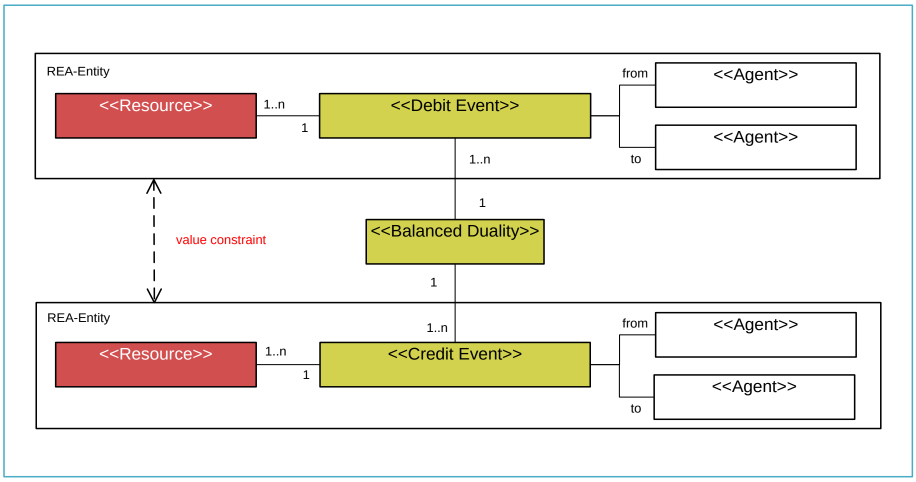

Figure 8. Reified Balanced Duality relationship – UML language

The Balanced Duality relationship not only holds in acquisition, conversion and revenue, but also in financing and investment transactions. To illustrate this point a debt financing transaction is considered. In debt financing financial instruments are involved. These instruments distinguish from physical resources and cash by having contractually defined future commitments. The inclusion of this future related information connected to financial resources is not required by the accounting standards and consequently it is not modeled in the REA-based ALE accounting model.

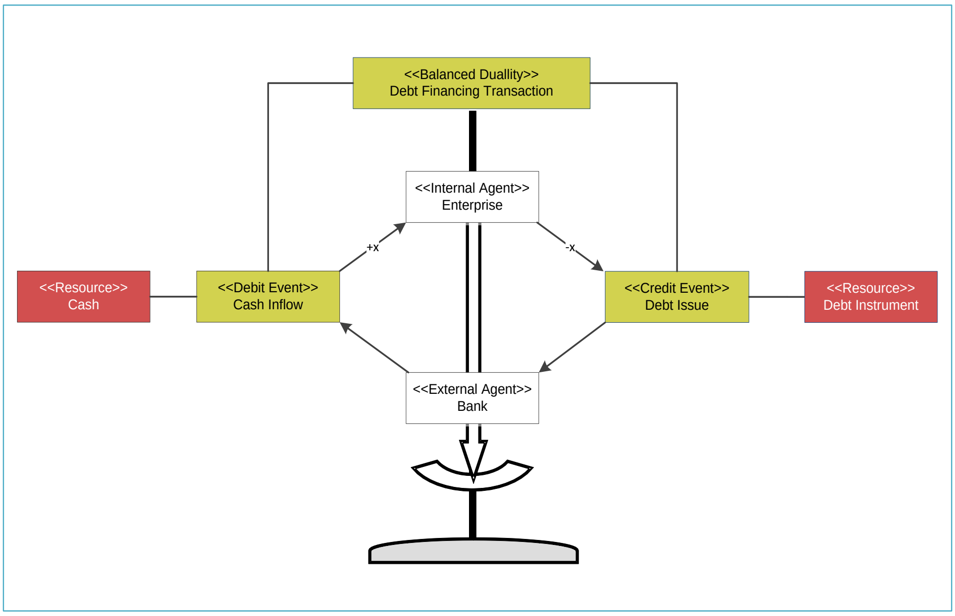

Figure 9. Balanced Duality relationship – debt financing transaction

In Figure 9 the Balanced Duality relationship is shown as a rectangle. It connects one debit event (cash inflow) on the left with one credit event (debt issue) on the right hand side. The value constraint within the balanced duality relationship can be seen again by the balancing of the variables *x*, which takes the sign +*x* for the debit event and –*x* for the credit event.

4 The OntoREA Accounting Model: Modeling the REA-based ALE Accounting Model in OntoUML

Guizzardi [6], [10] developed the OntoUML language as an UML extension that inherits its expressiveness from the Unified Foundational Ontology (UFO) and makes them accessible in UML class diagrams via stereotypes. All elements in OntoUML class diagrams, i.e. classes and associations, are *universals* with specific meta-properties. The universals are distinct from *individuals* as their instances. This distinction corresponds to the difference between *class* and *instance* in object oriented programming. The universals are distinguished into *endurants*, i.e. time existing entities with identity, vs. *perdurants*, i.e. temporal occurrences. For the endurant universals there is a hierarchical typification which results in a bushy tree [10]. Along the different paths of the tree subsequently more meta-properties are added. The leaves at the end of each path are the elements that can be used in the OntoUML language. They are the grey shaded elements in the last row of Figure 10.

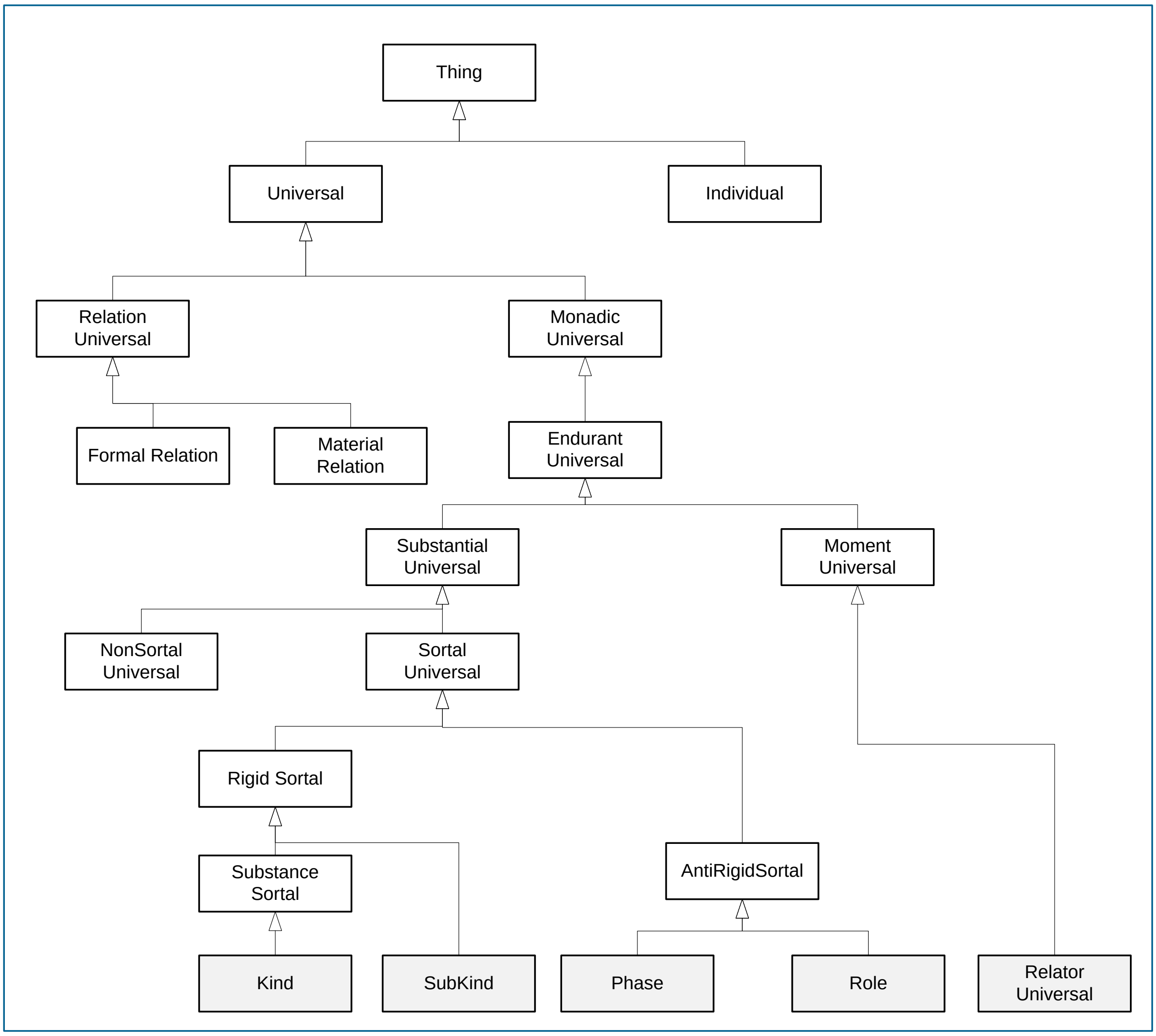

Figure 10. Relation types and (monadic) entity types – UFO excerpt

The hierarchical arrangement in the typification tree is based upon generalization (specialization) relationships. *Furthermore, universals of the same order can be related to one another through generalizations (or specialization) relations. This particular type of binary relation defines a universal as the parent (or the super-type) of another universal, the child (or the subtype). By specializing a universal, one defines a subset of individuals that instantiate the parent universal and share some characteristics* [22, p. 26].

After the aforementioned distinction of *Individuals* and *Universals*, Figure 10 shows that the latter are specialized into *Relation Universals* and *Monadic Universals*.

Relation Universals are defined as meta-concepts, that apply to groups of two or more *Individuals*. They get further differentiated into *Formal Relations* and *Material Relations*. While *Formal Relations* can hold between two *Individuals*, without the support of additional *Individuals*, *Material Relations* require an additional, external *Universal* called *Relator Universal*.

Monadic Universals conversely are meta-classes, whose instances can be instantiated by singular *Individuals*. They get specialized by *Endurant Universals,* which ensures the *Individual's* persistence throughout time, in contrast to *Perdurant Universals* (not shown here), that do not persist over time.

Substantial Universals and *Moment Universals* both generalize to *Endurant Universals*. *Substantial Universal's* instances are highly independent *Individuals*, they can exist alone where *Moment Universals* exist in other *Individuals* and depend on them. One specialization of *Moment Universal* is the *Relator Universal*. As mentioned above, it requires an external *Universal* for the *Material Relation* to hold.

The following distinction introduces the identity principle: While *NonSortal Universals* do not provide the identity principles for their instances, *Sortal Universals* do. Therefore, their instances are able to carry the identity principle. *Identity principle is a key feature of the UFO, which enables individuals to be distinguished from each other. Various universals define different identity principles and thus different ways how to distinguish their individuals* [23, p.4].

The specialization of *Sortal Universals* to *Rigid Sortals* and *AntiRigidSortals* define the meta-property of rigidity in a modal sense. The UFO distinguishes between rigidity and anti-rigidity as follows [6, p. 124]: *A rigid universal is one that applies to its instances necessarily, i.e., in every possible world.* In contrast to the rigid universal, an anti-rigid universal applies to its instances contingently. Illustrating examples for different modal meta-properties are given in [6, p. 289]: *Modal meta-properties play a fundamental role in conceptual modeling and ontology engineering. … there are a number of (meta)categories of types which are differentiated in terms of their modal meta-properties. For instance, while a* kind *such as* person *applies to its instances necessarily, a* phase *such as teenager or a* role *such as student apply to its instances only contingently. In other words, an instance of a person cannot cease to instantiate that type without ceasing to exist. In contrast, instances of a* phase *(teenager, living person) or* role *(student, husband, employee) can move in an out of the extension of these classes without any impact of their identity.*

A similar definition is as follows [23, p.5]: *Rigid universal's instances cannot cease to exist to be their instances without ceasing to exist by themselves*. On the contrary, anti-rigidity describes *universals that contain an instance in their extension in one world which is not included in the extension in another world*. *Rigid Sortals* are further specialized to *Substance Sortals,* which not only carry the identity principle, but also provide its own identity.

In conceptual modeling entity types and relationship types are the most fundamental constructs [24]. For the OntoREA accounting model to be developed the following entity types are of importance:

- Kinds are *rigid substance sortals* and provide their own identity principle (rather than just carrying it). *Kinds* are also considered as an OntoUML model's backbone [23].

- SubKinds are *rigid sortals* and do not provide their own identity principle, they are merely inheriting the principle from another *Substance Sortal*.
- Roles are *anti-rigid sortals* and therefore can change their instantiation in a modal sense according to an extrinsic generalization condition. Furthermore, Roles are relational-dependent, they have to rely on at least one other universal. Roles get their identity principle through the generalization relation from the instance of its parent universal.
- Phases are *anti-rigid sortals* as well with a significant distinction to Roles. Phases are relational-independent and so do not depend on another universal to function. Due to the predetermined disjoint and complete generalization sets, Phases, in contrast to Roles, change to other Phases according to their intrinsic generalization condition. As with Roles, Phases also get their identity principle through the generalization relation.

Next to the above-mentioned entity types the following relationship types will be important for the OntoREA accounting model to be developed:

- Relator Universals, are *moment universals* which represent the objectification of a relational property. Relator Universals are existentially dependent on a multitude of individuals, thus, mediating them. Relators are the foundation of the so-called Material Relations and act as truth-makers of the relation.
- Formal Relations hold directly between entities without requiring any intervening individual.

The remaining *Entity* and *Relationship Types* of the UFO are out of the scope, since they are not used in the discussed OntoUML models. The current and complete version of the UFO is specified in the UFO reference [25].

Now all needed UFO and OntoUML ingredients are given, so that the REA accounting model can be constructed in the OntoUML language. The traditional starting point of an OntoUML model is the identity providing *Kind* universal (substance sortal universal), which is represented in the OntoUML language as an accordingly stereotyped class (*Kind* class). In Figure 11 the *Kind* class is used for the Economic Resource, Economic Event and Economic Agent.

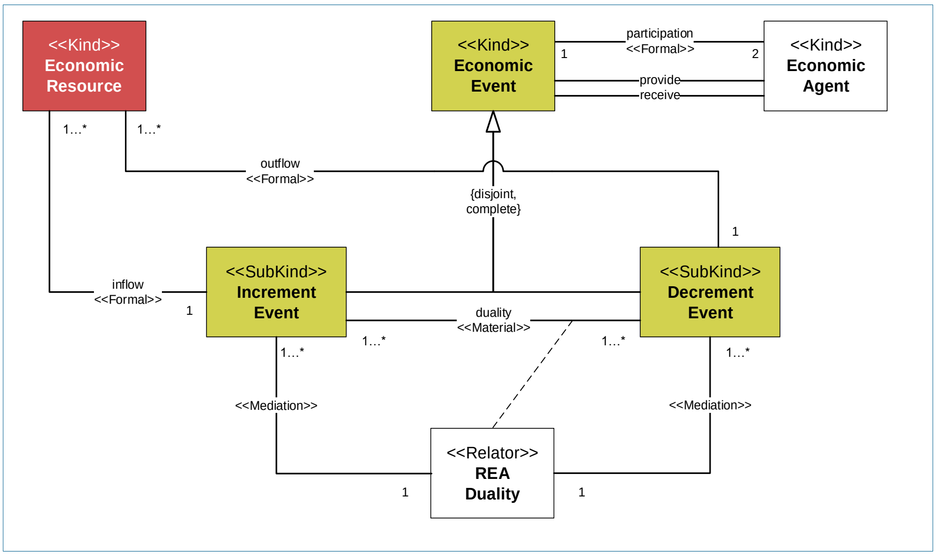

Figure 11. REA Accounting model – OntoUML language

The *Kind* class possesses the meta-properties so that they are independently existent and that they inherit their identity to their subclasses within a generalization relation. If the relation is rigid, a single individual is an instance of the super-class and the subclass in all possible worlds (constellations). If the relation is not rigid, a single individual may be an instance of both classes in one world, but not in another. These flexibilities, i.e. non-rigidities within the inheritance and the generalization already show the more flexible modeling possibilities in the OntoUML language compared to the rigid, i.e. non-modal UML language.

In the simplest case, all OntoUML elements are rigid in Figure 11. In this case the REA accounting model does not have any modality so that it corresponds to a model in the UML language. The temporal and modal changes of OntoUML elements are not needed in the REA accounting model as only REA-related snapshots of the business transactions are taken over time. But the situation changes – as will be seen later on – in the REA-based ALE accounting model.

In Figure 11 the REA accounting model includes several special modeling constructs:

- There is a typification of the *Kind* class Economic Event into the two *SubKind* classes Increment Event and Decrement Event via a disjoint and complete generalization set. In the mathematical sense such a set is a partition, so that an event can only be either an increment or a decrement event, i.e. there are only two possible states for the economic events to be in.
- The two disjoint subsets of the two *SubKind* classes are related by the *Relator* class REA Duality. This means that the duality relationship is reified via the *Relator* class that mediates between the increment and decrement events. This intermediation specifies the *Material* relationship called *duality*, which is shown in the form of an association between the two *SubKind* classes.
- The relationship between the Increment/Decrement Event and the Economic Resource is a *Formal* association named *inflow/outflow.* The distinction of *Formal* and *Material* relates to the reification of the relationship. *Material* relationships are reified and *Formal* relationships are not.
- The relationship between the Economic Event and Economic Agent called *participation* is a *Formal* association as well. The cardinalities in the figure indicate that two agents are involved in the relationship. The two additional lines say that one agent provides and the other receives.
- Finally it can be seen that all the cardinalities are specified in the REA accounting model.

Now the final step is taken, i.e. the translation of the REA-based ALE accounting model into the OntoUML language is performed. This translation is shown in Figure 12 and the resulting model is called the *OntoREA accounting model* due to its modeling in the OntoUML language.

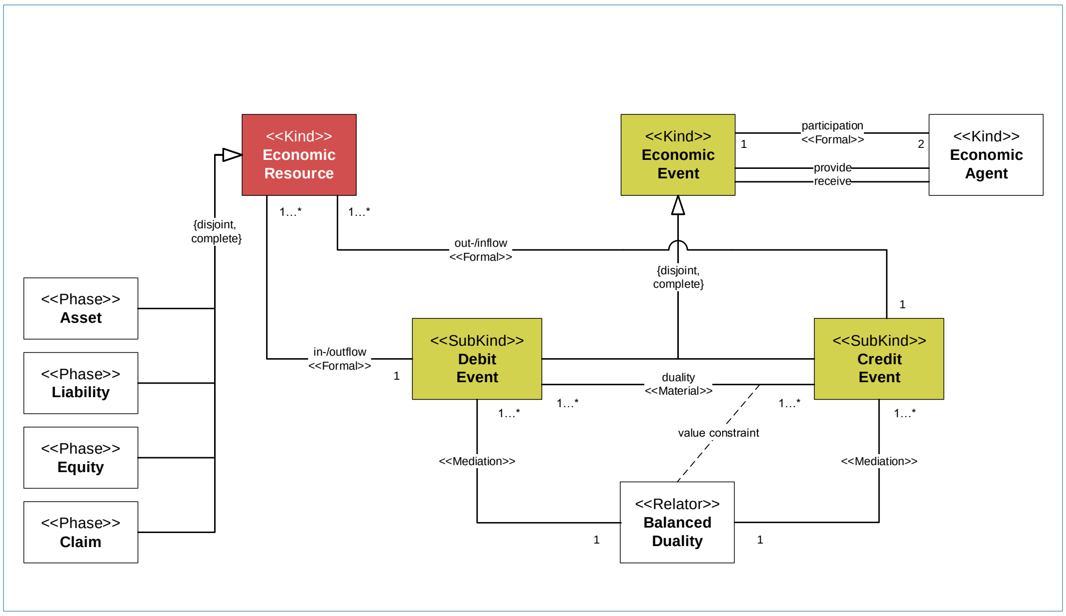

Figure 12. OntoREA Accounting Model – REA-based ALE Accounting in OntoUML

There are four remarks related to the difference between the REA accounting and the OntoREA accounting model:

1. The *Relator* class Balanced Duality is used instead of the REA Duality class. The difference lies in the value constraint, which is included in the Balanced Duality class.
2. Debit and Credit Event classes are used instead of the Increment and Decrement Event classes. The necessity for the change comes from the different resource types in the REA-based ALE accounting model, i.e. asset, liability and equity. An increase in liabilities and equity is related to a credit event, whereas an increase of assets relates to a debit event. Consequently increases of the different resource types are not associated with only one event type. The same holds true for decreases of different resource types.
3. The *Formal* relationships between the Economic Resource and the Debit Event as well as Credit Event are not any longer an inflow as well as outflow association. Instead in- and outflows can occur with debit as well as credit events. What really occurs depends on the type of the resource, i.e. asset, liability or equity.
4. An important additional OntoUML element is used for modeling of the resource types: the *Phase* element. The *Phase* class is an anti-rigid and a non-identity providing universal. Due to its anti-rigidity it possess a modal meta-property and it receives its identity from the superclass in the inheritance. The *Phase* class is needed to model the resource types with a modal meta-property. This property allows the change of resource phases over time. Due to the disjoint and complete generalization set the assignment of the resources to the different phases is modeled as a partition. This means that each individual resource instance is assigned to one phase. Over time the assignment can change. At first glance this might be confusing as normally the assignment stays the same over time. Such a rigid, i.e. non-modal behavior is typical for most assets, liabilities and equity. But a clear exemption are claims. According to the definition in the refined REA-based ALE accounting model, claims are negatively defined by imbalances in the balanced duality relationship that are neither assets, nor liabilities, nor equity. When claims materialize they convert to their corresponding resource type. It has to be noted that this is only one example of a modal behavior of resource types over time. There are more such resources out there especially in the context of derivative financial instruments.

For technical validation purposes the OntoREA accounting model presented in Figure 12 was modeled in the *Sparx Enterprise Architect* software application equipped with the OntoUML plugin as well. As the modeling did not show any problems, it can be concluded that the model fulfills all UFO axioms [11, p. 8]. Furthermore it is also possible to validate the substance of the OntoREA accounting model by comparing its underlying modeling decisions with the modeling constructs chosen in the reengineered REA enterprise ontology by Gailly et al. [11].

The middle column in Table 1 shows the UFO universals selected by Gailly et al. in their OntoUML model. Their modeling decisions with respect to the REA primitives relevant for the comparison are as follows:

- An *Economic Resource* is modeled as an UFO *Role* class, an *anti-rigid sortal* universal, carrying but not providing a criterion of identity for its instances. Gailly et al. justify the anti-rigidity that an economic resource is not of the type *Economic Resource* in every possible world. It is mentioned that if the economic resource perishes it no longer has value. Furthermore, if an economic resource is no longer under control of an economic agent, Gailly et al. argue, it no longer is an economic resource. The properties, that legitimate the anti-rigidity are therefore *being under control of an economic agent* and *having economic value*. Moreover, *these properties are considered as extrinsic properties, that have their origin in some kind of event or relationship* [11, p. 8].
- The *Economic Event* is modeled as an UFO *Relator* class, a non-sortal anti-rigid mixin universal. Justified by *that according to its definition, the Economic Event is not a*

standalone kind but represents a mediating entity for the relation between an economic resource and two economic agents (inside and outside), i.e. glues them together [11, p. 9].

- The *Economic Agent* is modeled as an UFO *Role Mixin* class. It is not supposed to carry a criterion of identity for its instances but instead represents an abstraction of the roles played, namely accountability of the inside agent and participation of the outside agent.
- The concept of *Duality* is modeled as *Formal relation* with the reasoning that they have some similar characteristics of the entities they connect.

Table 1. Mapping of REA Primitives onto OntoUML constructs

REA primitives	**Mapping in Gailly et al. [11]**	**Mapping in OntoREA Accounting Model**
Economic Resource	Role	Kind
• Asset/Liability/Equity/Claim	-	• Phase
Economic Event	Relator Universal	Kind
• Increment Event	• -	• SubKind
• Decrement Event	• -	• SubKind
Economic Agent	RoleMixin	Kind
• Inside Agent	• Role	-
• Outside Agent	• Role	-
Duality	Formal relation	-
Balanced Duality	-	Material relation

The last column in Table 1 shows the UFO universals used in the OntoREA accounting model (Figure 12). There are some remarkable differences which are explained as follows:

- The legal requirement in the ALE accounting domain to record the accounting information of business transactions necessitates (rigid) substantial sortal universals that provide the identity principle for their instances. In the REA-based ALE accounting context this relates to the *Economic Resource*, the *Economic Event* as well as the *Economic Agent* which consequently are modeled in OntoUML in form of *Kind* classes. These three classical REA primitives consequently constitute the ontological backbone of the OntoREA accounting model.
- The *Economic Resource* is typified into *Phase* classes according to the economic value specialization condition for distinguishing between Asset, Liability, Equity and Claim whereas this condition is considered as an intrinsic property of the resources. The argument for this lies in the determination of the resource's economic value according to the resource's intrinsic quality property. Furthermore the modal property of anti-rigidity with respect to the Claim is not of a deterministic but of a probabilistic nature. This means that Claim instances do not have to switch into another phase in a temporal deterministic sequence (like, e.g. transition from childhood to adulthood), but can change randomly (e.g. between accounts receivable and product liability in both directions).
- The *Economic Event* is typified into rigid *SubKind* classes for the Debit Event and the Credit Event. Due to the rigidity the Debit Event and the Credit Event do not change over time. They inherit the identity principle of the Economic Event and they are mediated ("married") via the *Relator* class Balanced Duality. Furthermore it is important to note that the *Economic Event* and its typification are not modeling activities within perduring business transactions, but instead, they are important for recording the occurence of such transactions. The recording of the *Economic Event* has to be rigid in order to assure trackability of the transactions over time.
- The *Balanced Duality* is a *material relationship* due to the contracting that underlies business transactions and mediates between debit and credit events.

- The *Economic Agent* is – as already mentioned – of an UFO *Kind* class so that it provides the identity principle and can be recorded. Its typification is left unspecified. Depending on the identity principle, the (anti-)rigidity and the intrinsic or extrinsic nature of the specialization properties, different UFO constructs can be adequate.

5 Conclusions

The primary research objective addressed in this article relates to a deeper anchoring of REA-based accounting models into the ALE accounting domain. For this purpose the OntoREA accounting model was developed by translating the REA-based ALE accounting model into an adequate model formulated in the OntoUML language. The adequacy of the OntoREA accounting model stems from the inclusion of the balanced duality relationship which is an essential primitive of the ALE accounting domain. Next to that, it contains a sharper definition of claims which is compliant within the ALE accounting context. Finally the OntoREA accounting model is expressed in the OntoUML language. By this, the rigidity of the UML language is extended to allow anti-rigid typifications, e.g. in form of temporal and modal changes of the economic resources over time.

The actual benefits of a conceptual modeling in the OntoUML language can be directly observed by comparing the REA-based ALE accounting model in Figure 6 with the OntoREA accounting model in Figure 12. The OntoREA accounting model is not only quantitatively more expressive but also qualitatively. Here are the following quantitative enhancements:

- The complete specification of all relationship cardinalities.
- The integrated reification of the balanced duality relationship.
- The integrated typification that was demonstrated for the event and resource types.

The qualitative enhancement relates to the additionally included ontological information in form of *Kind*, *SubKind*, *Phase*, *Relator*, *Material*, *Formal*, *disjoint* and *complete*. This added ontological information characterizes the very nature of all the elements (universals) in the REA-based accounting domain with respect to dependent and independent existence, possession and providing of identity, rigidity and anti-rigidity of instantiations as well as temporality and modality of the universals. In this light, new ways of thinking are available, for instance: in the resulting OntoREA accounting model the resources, events and agents are the identity providing universals. The event universals are rigid over time whereas the resource universals are non-rigid so that a modal behavior can be specified like, e.g. in the case of claims.

Summing up, the proposed model provides the following benefits:

- The identification of the balanced duality relationship and its integration as a *Relator* class mediating between credit and debit events.
- The rigid and identity principle providing economic resources, economic events and economic agents as *Kind* classes.
- The rigid typification of economic events into the *SubKind* classes Debit Event and Credit Event.
- The anti-rigid typification of economic resources into the *Phase* classes Asset, Liability, Equity and Claim.
- Enhancement of the OntoREA accounting model's ALE accounting compliance.

Accordingly, the inclusion of the ontological meta-properties in the OntoREA accounting model assures compliance and gives an improved expressiveness, which can be achieved neither in the UML nor in the ER languages. This advantage also prevails vis-à-vis domain specific languages as the DSL languages are normally constructed in Gruber's ontology understanding so that the ontological meta-properties are missing.

It is interesting to note that the REA-based ALE accounting model is just the first step where the benefits of the OntoUML language are prevailing. It can be expected that the full benefits of the OntoUML languages will be seen in more advanced models within the REA-based accounting domain like, e.g. the REAC-based accounting model [12] that includes finance requirements and the REA business management model [19] that includes managerial planning and control systems. In these advanced models the temporal and modal changes are especially important due to the uncertainty that lies ahead of the conventional accounting focus, but that has to be captured in the business management context.

Finally, an interesting idea for future research related to the REA enterprise ontology comes from an anonymous referee. Instead of only using enduring entities from the UFO-A for all REA primitives, it seems worthwhile to model economic events via perduring entities from the UFO-B and economic agents via agents as described in the UFO-C [6], [24], [25]. By doing this, enterprise models can be developed that cover a much broader range of aspects compared to the more narrow compliance requirements within the ALE accounting domain.

References

[1] W.E. McCarthy, “The REA Accounting Model - A Generalized Framework for Accounting Systems in a Shared Data Environment,” *The Accounting Review*, vol. LVII, no. 3, pp. 554–578, 1982.

[2] G.L. Geerts and W.E. McCarthy, “An ontological analysis of the economic primitives of the extended-REA enterprise information architecture, ” *Int. J. Account. Inf. Syst.*, vol. 3, no. 1, pp. 1–16, 2002. [Online] Available: https://doi.org/10.1016/S1467-0895(01)00021-5

[3] G.L. Geerts and W.E. McCarthy, “Policy Level Specifications in REA Enterprise Information Systems,” *J. Inf. Syst.*, vol. 20, no. 2, pp. 37–63, 2006. [Online] Available: https://doi.org/10.2308/jis.2006.20.2.37

[4] T.R. Gruber, “A translation approach to portable ontology specifications,” *Knowl. Acquis*., vol. 5, no. 2, pp. 199–220, 1993. [Online] Available: https://doi.org/10.1006/knac.1993.1008.

[5] Y. Wand and R. Weber, “An Ontological Model of an Information System,” *IEEE Trans. Softw. Eng.*, vol. 16, no. 11, pp. 1282–1292, 1990. [Online] Available: https://doi.org/10.1109/32.60316

[6] G. Guizzardi, “Ontological Foundations for Structural Conceptual Model,” 2005.

[7] E.J. Lowe, “The Four-Category Ontology: A Metaphysical Foundation for Natural Science,” *Dialectica*, vol. 60, no. 4, pp. 513–518, 2006. [Online] Available: https://doi.org/10.1111/j.1746-8361.2006.01078.x

[8] G. Guizzardi and G. Wagner, “Towards Ontological Foundations for Agent Modelling Concepts Using the Unified Fundational Ontology (UFO),” *Agent-Oriented Inf. Syst. II.*, 3508, pp. 110–124, 2005. [Online] Available: https://doi.org/10.1007/11426714_8

[9] N. Guarino and C.A. Welty, “An overview of OntoClean,” in: *Handbook on Ontologies*, pp. 201–220 Springer International Publishing, 2009. [Online] Available: https://doi.org/10.1007/978-3-540-92673-3_9

[10] OntoUML: Specification 1.0. [Online] Available: http://ontology.com.br/ontouml/spec/.

[11] F. Gailly, G. Geerts and G. Poels, “Ontological Reengineering of the REA-EO Using UFO,” *OOPSLA Work. Ontol. Softw. Eng*., October, 2009.

[12] W.S.A. Schwaiger, “The REA Accounting Model: Enhancing Understandability and Applicability,” in: Conceptual Modeling: 34th International Conference, ER 2015, Stockholm, Sweden, October 19–22, 2015, Proceedings. pp. 566–573 Springer International Publishing, 2015. [Online] Available: https://doi.org/10.1007/978-3-319-25264-3_43

[13] M. Romney and P.J. Steinbart, “Accounting Information Systems,” Pearson Higher Education AU, 2012.

[14] C.L. Dunn, J.O. Cherrington and A.S. Hollander, “Enterprise information systems: A pattern-based approach,” McGraw-Hill/Irwin, 2005.

[15] M. Brambilla, J. Cabot and M. Wimmer, “Model-Driven Software Engineering in Practice,” 2012. [Online] Available: https://doi.org/10.2200/s00441ed1v01y201208swe001

[16] M. Völter, T. Stahl, “Model-driven software development: technology, engineering, management,” John Wiley & Sons, 2013.

[17] R. Pergl, T.P. Sales and Z. Rybola, "Towards ontoUML for software engineering: From domain ontology to implementation model," in: *Lecture Notes in Computer Science* (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). pp. 249–263, 2013. [Online] Available: https://doi.org/10.1007/978-3-642-41366-7_21

[18] Standardization/International, E.C.I.O. for: "Information Technology—Business Operational," View—Part 4: "Business Transactions Scenarios—Accounting and Economic Ontology," ISO/IEC FDIS. 15944, 2007. [Online] Available: https://www.iso.org/obp/ui/#iso:std:67199:en

[19] W.S.A. Schwaiger, "REA Business Management Ontology: Conceptual Modeling of Accounting, Finance and Management Control," in: S. España, et al. (eds.) Proceedings of the CAiSE'16 Forum, at the 28th International Conference on Advanced Information Systems Engineering (CAiSE 2016), 2016. [Online] Available: http://ceur-ws.org/Vol-1612/paper6.pdf

[20] W.S.A. Schwaiger and M. Abmayer, "Accounting and Management Information Systems," Proc. Int. Conf. Inf. Integr. Web-based Appl. Serv. - IIWAS '13, pp. 346–352, 2013.

[21] C. Horngren, et al., "Accounting," Pearson Higher Education AU, 2012.

[22] T.P. Sales, "Ontology Validation for Managers," 2014, [Online] Available: https://www.researchgate.net/publication/268220197_Ontology_Validation_for_Managers

[23] Rybola, Z. and Pergl, R.: Towards OntoUML for Software Engineering : Introduction to the Transformation of OntoUML into Relational Databases.

[24] G. Guizzardi, G. Wagner, J.P.A Almeida and R.S.S. Guizzardi, "Towards ontological foundations for conceptual modeling: The unified foundational ontology (UFO) story," *Appl. Ontol*., vol. 10, no. 3–4, pp. 259–271, 2015. [Online] Available: https://doi.org/10.3233/ao-150157

[25] T. Sales, P.P.F. Barcelos and G. Guizzardi, "Identification of semantic anti-patterns in ontology-driven conceptual modeling via visual simulation," 4th Int. Work. Ontol. Inf. Syst. (ODISE 2012), Graz, Austria. January 2012. [Online] Available: https://www.researchgate.net/publication/260545296_Identification_of_Semantic_Anti-Patterns_in_Ontology-Driven_Conceptual_Modeling_via_Visual_Simulation

[26] Ontology Project: UFO-A Specification. [Online] Available: http://ontology.com.br/ufo-a/spec/

Additional information about the article:

Author ORCID iD	Christian Fischer-Pauzenberger – www.orcid.org/0000-0002-9071-9523 Walter S.A. Schwaiger – www.orcid.org/0000-0003-1868-7018
Article history	Received 16 September 2016 Last revision received 16 February 2017 Accepted 31 May 2017 Available online 31 July 2017
Article PII	S225599221700063X