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An Event-Centric Knowledge Graph Approach for Public Administration as an Enabler for Data Analytics

Dimitris Zeginis * and Konstantinos Tarabanis

Department of Business Administration, University of Macedonia, 54636 Thessaloniki, Greece; kat@uom.edu.gr
* Correspondence: zeginis@uom.edu.gr

Abstract: In a continuously evolving environment, organizations, including public administrations, need to quickly adapt to change and make decisions in real-time. This requires having a real-time understanding of their context that can be achieved by adopting an event-native mindset in data management which focuses on the dynamics of change compared to the state-based traditional approaches. In this context, this paper proposes the adoption of an event-centric knowledge graph approach for the holistic data management of all data repositories in public administration. Towards this direction, the paper proposes an event-centric knowledge graph model for the domain of public administration that captures these dynamics considering events as first-class entities for knowledge representation. The development of the model is based on a state-of-the-art analysis of existing event-centric knowledge graph models that led to the identification of core concepts related to event representation, on a state-of-the-art analysis of existing public administration models that identified the core entities of the domain, and on a theoretical analysis of concepts related to events, public services, and effective public administration in order to outline the context and identify the domain-specific needs for event modeling. Further, the paper applies the model in the context of Greek public administration in order to validate it and showcase the possibilities that arise. The results show that the adoption of event-centric knowledge graph approaches for data management in public administration can facilitate data analytics, continuous integration, and the provision of a 360-degree-view of end-users. We anticipate that the proposed approach will also facilitate real-time decision-making, continuous intelligence, and ubiquitous AI.

Keywords: continuous intelligence; data analytics; event-centric; knowledge graphs; public administration

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1. Introduction and Motivation

In a continuously evolving environment, organizations, including public administrations, need to quickly adapt to change and make decisions in real-time. Traditionally, IT solutions adopted by organizations store only historical state-based information; however, in order to decide in real-time, organizations also need dynamic and real-time context that can be achieved by adopting an event-native mindset [1].

Public administrations (PA) around the globe produce and handle a vast amount of data that are mainly the outcome of interactions of end-users (e.g., citizens and businesses) with public services [2]. For example, a citizen uses a public service in order to register a birth at the responsible public authority, while a business uses a public service for regular/annual VAT declarations. However, PAs usually store only information related to the resulting state of these interactions (e.g., the outcome of the public service provision), failing to also capture the dynamics of change. Additionally, the produced data are usually scattered in numerous siloed databases developed by different departments and divisions. The prevalent way of structuring these databases is based on the area of jurisdiction of PA divisions. By evaluating the focus of PA, one finds that most interactions involve only a few end-user types such as citizens or businesses. However, the current siloed and fragmented

way of structuring data hinders PAs from providing a comprehensive overview of the end-users considering their interactions.

Knowledge graphs have gained increasing popularity in the past couple of years since they are able to structure large collections of data in a meaningful way. Typically, knowledge graphs represent a static state of the world including facts about persons or organizations (e.g., birth date, birth place, education, occupation) and do not focus on the dynamics and changes over time (e.g., changes in occupation over time). Recently, a new approach of event-centric knowledge graphs (ECKG) [3] has been proposed to capture this dynamic knowledge, which requires considering "events" as first-class entities for knowledge representation. A number of ECKG models have already been proposed in the literature; however, they are generic and cannot address all the specific needs of the public administration domain.

The main goal of this paper is to propose an ECKG approach for the holistic data governance of all data repositories in PA. Towards this direction, the paper proposes an ECKG model for the domain of public administration and assesses the possibilities/advantages that arise through a case study on the Greek public administration. Therefore, this paper aims to answer the following research questions: (i) How can event-centric knowledge graphs be applied in public administration? and (ii) What possibilities/advantages arise from the use of an ECKG approach to data management in public administration?

The paper's results show that the adoption of an event-native approach by a public administration for data management can facilitate data analytics, the provision of a 360-degree-view of end-users, and continuous integration of data not just in representation, but also in context and time.

The rest of the paper is structured as follows: Section 2 presents related work based on a literature review that aims to identify core concepts and needs for the ECKG model. Section 3 describes the proposed ECKG model for PA. Section 4 applies the model to the case of the Greek public administration in order to validate it (Section 4.2) and showcase the possibilities/advantages that arise (Section 4.3). Section 5 provides a discussion of the results. The paper presents concluding remarks in Section 6.

2. Related Work

This section presents related work including a literature review, on event-centric knowledge graph models, existing populated graphs, and potential applications/analytics, that mainly aims to identify core concepts related to event representation (Section 2.1), a literature review on public administration models that aims to identify the core entities of the domain (Section 2.2), and a theoretical analysis of concepts related to events, public services, and effective public administration in order to outline the context and identify the public administration domain needs for event modeling (Section 2.3).

2.1. Event-Centric Knowledge Graphs

Recently, knowledge graphs (KGs) have been proposed as a paradigm to structure large collections of data in a meaningful way in the form of interrelated facts about entities. KGs rely on semantic web technologies such as RDF [4] (a model for data interchange on the Web) and SPARQL [5] (a language to express queries on RDF data). These technologies use URIs to name things and their relationships which are expressed as "triples" <subject, predicate, object>.

Existing popular open KGs include DBpedia [6], YAGO [7], and Wikidata [8] which mainly contain static facts about persons (e.g., name, birth date) or organizations (e.g., foundation date, owner). Recently, a new approach for event-centric knowledge graphs (ECKG) has been proposed that can also capture the dynamics of data. Various models and approaches have already been proposed in the literature in order to represent events and their context as ECKGs. Table 1 presents a number of relevant models which have been identified based on a non-exhaustive literature review by the authors.

Table 1. Event-centric knowledge graph models.

Model	Structure	Domain	Agent	Time	Place	Event-Event Relations	Event Result
The Event Ontology [9,10]	Graph	cross-domain	✓ (event starter/receiver)	✓	✓	✓ (sub-event)	✓ (product)
ABC ontology [11]	Graph	cross-domain	✓	✓	✓	✓ (sub event)	✓
Event-Based Approach [12]	Graph	cross-domain	✓ (agent—initiates, patient—undergoes, role—other)	✓	✓	✓	✓
UFO-B [13,14]	Graph	cross-domain	✓ (participation—role)	✓	✓	✓ (has-part, causes, time relations e.g., precedes)	✓ (situation before/after event)
CPEV [15]	Graph	cross-domain	✓ (participation—role)	✓	✓	✓ (sub/parent event, previous/next event)	✗
F–A model [16]	Graph	cross-domain	✓ (role)	✓	✓	✓ (included in, causality, correlation)	✗
LODE [17]	Graph	cross-domain	✓ (role)	✓	✓	✓ (sub-event, has part)	✗
SEM [18]	Graph	cross-domain	✓ (actor, role)	✓	✓	✓ (sub-event)	✗
schema.org [19]	Graph	cross-domain	✓ (various roles e.g., actor, attendee, contributor etc.)	✓	✓	✓ (sub/super event)	✗
CIDOC CRM [20]	Graph	Cultural heritage	✓	✓	✓	✗	✗
EventsML [21]	Graph	News	✓	✓	✓	✓ (broader/narrower)	✗
TOGAF [22]	Graph	Enterprise Architecture	✓ (actor, role)	✗	✗	✗	✓ (product)
ECKG PA [23]	Tree	Public Administration	✓	✓	✓	✓ (sub-event)	✓ (public service)
HRM PA [24]	Tree	Public Administration	✓	✓	✓	✓ (sub-event)	✓ (agent state)
Event Model Multimedia [25]	Graph	Multimedia	✓	✓	✓	✓ (sub-event, causing event)	✗
EEKG [26,27]	Tree	Health	✓	✓	✗	✗	✗

Most of these models are cross-domain; however, there are some that focus on specific domains (e.g., news [21], public administration [23,24], multimedia [25], health [26]). The analysis of the models identified a number of core concepts and relations, namely, the Agent, Time, Place, Event–Event relations, and Event result. The Event concept appears in all the models, however with different semantics. For example, some models have a more generic perspective considering the event as something that happens at a particular place and time [9]; others consider the event as a transition between situations [11], while some others focus only on public events (e.g., concerts) [15]. The concept Agent appears in all the models as a participant to an Event. In some cases [9,12], two different types of Agent are distinguished, the Agent that initiates the Event and the Agent that receives/undergoes the Event. Additionally, some models enable the use of other types of Agents using different Roles [12,13,15,16,18,22]. The concepts Time and Place are fundamental for the definition of the Event and appear in almost all the models. Various relations between Events are also considered including sub/super events, time relations (previous/next event), causality, and correlation. Finally, the Result of the Event is also modeled in some of the models. The semantics of the Result is highly related to the definition of the Event concept or to the domain on which the model focuses on. For example, in the cases where the Event is considered as a transition between situations, the Result is the situation after the Event [11,13], while in the models targeting the Public Administration domain, the Result is associated with the consumption of a Public Service [23,24].

The identified models can also be categorized based on the structure they adopt to model knowledge. Most of the models adopt a graph structure. The graph structure is very flexible but lacks performance when used at a large scale, e.g., when identifying all the Events of an Agent. Towards this direction, some models [23,24,26,27] propose the representation of entities and events as hierarchical trees having the Agent as a root. This approach is applicable to organizations, including PA, that handle interactions (i.e., events) with only a few types of agents (e.g., citizens, businesses). This tree-like structure is beneficial from a performance point of view and also enables organizations to provide a comprehensive overview of these Agent types.

Based on the proposed models, a number of populated ECKGs have been developed in various domains. Specifically, based on the SEM model [18], various cross-domain ECKGs [28–30] and domain-specific ECKGs, i.e., tourism [31] and news [3], have been developed. Most of the ECKGs [3,28–31] capture information about the Events (e.g., Agent, Time, Place), while two of them capture temporal Event–Event relations [32,33]. Table 2 provides more information about the populated ECKGs that have been identified based on a non-exhaustive literature review by the authors.

Table 2. Populated event-centric knowledge graphs.

Name	Domain	Base Model	Description
EventKG [28]	cross-domain	SEM [18]	Event-centric information extracted from Wikidata, DBpedia and YAGO
EventKG+Click [29]	cross-domain	SEM [18]	EventKG plus information on user interactions with events, entities, and their relations derived from Wikipedia clickstream
OEKG [30]	cross-domain	SEM [18]	A multi-domain open event knowledge graph (includes EventKG and EventKG+Click)
ASER [32]	cross-domain	-	Includes Temporal, contingency, comparison, expansion, and co-occurrence relations between events
Event-centric Hainan tourism KG [31]	Tourism	Extend SEM [18]	Temporal and spatial information of tourists' trips
Chinese travel domain event evolutionary graph [33]	Tourism	-	Includes Temporal relations between events
Event-centric knowledge graph from news [3]	News	SEM [18]	The sources for news used are: WikiNews, FIFA WorldCup, Cars, and Airbus Corpus

Besides the populated ECKGs, a number of systems/pipelines have also been developed in order to create ECKG data based on documents/text [34,35], video data [36], and remote sensing information [37]. Finally, the increased popularity of ECKGs has enabled the development of relevant applications including the prediction of future events given the existing ECKG [38–41], the generation of event timelines [42], question answering systems [43], and recommendation systems [31].

2.2. Core Entities in Public Administration

In order to identify the core entities (Agents) that interact with PA, we conducted an analysis of existing PA models and ontologies. This analysis included models and ontologies proposed in the academic literature (e.g., [44,45]) as well as national models and standards applied in real-life settings (e.g., [46,47]). The identification of relevant models and ontologies is based on an existing European Commission study about national PA models [48] and on a literature review paper related to PA ontologies and models [2] (the literature review paper also provides an initial analysis of the models). The identified models and ontologies were then studied and analysed by the authors in order to identify the relevant core entities. Table 3 presents the outcome of this analysis. Three main core entities have been identified, namely: "citizen", "business", and "public administration". From an ECKG point of view, these core entities are the agents that participate in an event.

Table 3. Core entities identified from existing public administration models and ontologies.

Public Administration Model	Citizen	Business	Public Administration	Life/Business Event
Governmental Markup Language (GovML) [44]	✗	✗	✗	✓
SmartGov model [49]	✓	✓	✗	✗
E-GOV Public Services Ontology (E-GOV PSO) [45]	✓	✓	✗	✓
Switzerland Data Model for Public Administration (DMPA) [46]	✓	✓	✓	✗
Governance Enterprise Architecture (GEA) [50]	✓	✓	✗	✗
DIP model [51]	✓	✗	✗	✓
OneStopGov model [52]	✓	✗	✗	✓
Access-eGov model [53]	✗	✗	✗	✓
Government to Businesses Model (G2BM) [54]	✗	✓	✗	✗
eGovernment Knowledge Interoperability Ontology (eGKI) [55]	✓	✓	✓	✗
Life Event Ontology (LEO) [56]	✓	✗	✗	✓
Core Public Service Vocabulary (CPSV) [47,48]	✗	✗	✓	✓

Another interesting outcome of the analysis is that events usually occur under the scope of broader categories called "life-events" and "business-events". The literature has already identified "life events" and "business events" as situations experienced by humans/businesses which raise specific needs (e.g., having a baby, starting a professional activity, getting married) that require the provision of a group of public services in order to fulfill these needs [57]. For example, "having a baby" is a life event that requires the provision of a group of public services, e.g., "birth registration", "obtaining child allowance", etc. Thus, life events and business events can also be considered as groupings of ECKG events for PA.

2.3. Public Administration Context and Needs for Event Modeling

Some of the main goals of public administration are to effectively manage public resources, deliver essential public services, and implement policies to improve citizens' well-being [58]. In this context, the notion of effective public administration has already been studied in the literature within various contexts and perspectives (e.g., environmental protection [59], smart cities [60], administrative law [61]) and is crucial since it refers to the effective management of public resources to achieve societal goals. One of the enablers for effective public administration of special importance in the AI era is effective data management which has the potential to enable informed decision making in public administration [62].

A large portion of public administration data resolve around events which are related to the interactions of end-users (i.e., citizens, businesses). Three main types of interactions exist in the context of public administration [63]: (i) fulfillment of financial obligations of the citizen/business to PA, e.g., payment of taxes, (ii) interaction of the citizen/business with PA for non-financial reasons, e.g., issuing a passport, birth registration, (iii) fulfillment of financial obligations of PA to the citizen/business, e.g., payment of unemployment benefits and pensions. All these interactions are realized through the provision of public services, e.g., the payment of income taxes is realized through the interaction of citizens with a financial public service and birth registration is realized through the interaction of a citizen with a non-financial public service.

The development of public services is based on underlying models and standards that are considered main enablers for promoting the interoperability and quality of public service provision [2]. Embracing the need for a standard public service model, the European Commission has developed the Core Public Service Vocabulary Application Profile (CPSV-AP) [47]. CPSV-AP enables the description of public services related to business and life events, to facilitate the setting up of catalogues of services oriented to businesses and citizens. It consists of concepts defining a public service including the input evidence required for the service, produced output, cost, relevant legislation that governs the service, public organization responsible for the delivery of the service, available channels (e.g., online services, phone, walk-in centres), contact point information, and requirements/prerequisites for the service (e.g, be an adult).

An important issue regarding the provision of public services is their "versioning"/variants [64]. Different public service versions/variants may be needed for different profiles/circumstances of citizens and may require different inputs, have different cost, or produce different outputs [65]. For example, the public service "Issuing passport" has different versions/variants in case the citizen is an adult or minor. More specifically, the issuing of a passport to a minor may need different inputs (e.g., the ID card of the parent) compared to the issuing of a passport to an adult which would have a different output (e.g., passport with different duration) or a different issuing cost. The number of versions/variants may be high, e.g., the public service for issuing a passport in Greece has more than 20 versions [66].

The CPSV-AP cannot handle the different public service versions/variants efficiently [67]. The versions/variants can be modeled as different public services, increasing exponentially the public service descriptions that need to be created as well as duplicating various informa-

tion (e.g., information about the public organization or the legislation that remains the same among the versions). Another option is to create one public service description encapsulating all the versions (including input/cost/output); however, in this case the information that distinguishes one version from another is missing. Additionally, CPSV-AP cannot adequately model information about the actual public service provision. For example, CPSV-AP cannot model information about the citizen that requested the service, the date/time of provision, or the specific service version provided (e.g., input/output/cost).

3. An ECKG Model for Public Administration

This section presents the proposed ECKG model for PA (Figure 1) that can be used in order to populate event-centric knowledge graphs. A tree structure (similar to [23,24,26,27]) having the Agent as a root is selected since it is more efficient because PA handles events with only a few Agent types. In the context of PA, events are considered as the interactions of the core entities (Agents) with a public service. Thus, the association of an Event with a Public Service (and where applicable, with the public service version/variant) is important.

The structure and concepts of the model are based on: (i) the outcome of the analysis of existing ECKG models (Section 2.1) that identifies concepts/properties related to Events, (ii) the outcome of the analysis of existing PA models and ontologies (Section 2.2) that identified the core entities (Agents) in the context of PA, and (iii) the analysis of events and their context in the public administration and of CPSV-AP as a standard public service model (Section 2.3). The proposed model includes three main levels:

- Level 1 is the core entity (Agent) that serves as the root of the tree. For PA, the core entity can be either a citizen, a business, or a PA entity.
- Level 2 includes the Events associated with a timestamp. The Events can be either high-level such as "life-event" or "business-event" (e.g., birth), or more fine-grained Events (e.g., birth registration) related to the provision of specific public services. The high-level life events may have one or more fine-grained sub-events.
- Level 3 contains PA domain knowledge bases including CPSV-AP-based public service descriptions. These knowledge bases are needed to add context to the ECKG.

We assume that CPSV-AP models all variations using the same public service definition; thus, it is the role of the proposed ECKG model to pinpoint the exact version/variant that is actually provided. The other option would be to model each variation separately but this would result in an exponential increase in public service descriptions.

Towards this direction, CPSV-AP concepts need to be distinguished as event aware (may vary among public service versions/variants) and event-agnostic (remain the same among public service versions/variants), and associate the Event only with the event-aware ones. An indicative classification is the following. The event-agnostic concepts include the "Public Service", "Public Organization", "Legal Resource", and "Contact Point", while the event-aware concepts include the "Output", "Evidence", "Channel", "Cost", and "Criterion Requirement". This classification of concepts may vary for different public service implementations. For example, different "Public Organizations" may be responsible for delivering different public service versions/variants; in this case, "Public Organization" would be categorized as an event-aware concept. Any changes to the classification do not affect the approach and structure of the proposed ECKG model.

The fine-grained events (level 2) that are related to the provision of public services are associated with a "Public Service" using the predicate "is resolved by" and with all the event-aware concepts of CPSV-AP (e.g., Cost, Channel, Output, Evidence) using the predicates "include cost", "include channel", etc. This way of modeling enables the association of events with the specific public service version/variant that is provided. It should be noted that there is a need to associate the event-aware concepts with two predicates (e.g., "include cost" and "has cost"). One is part of the public service description (e.g., "has cost") and is independent of events, while the other (e.g., "include cost") aims to associate an event with the specific concept as part of the public service version that was provided. All the event-agnostic concepts (e.g., Public Organization responsible for delivering the public

service, legal resource) can be retrieved directly through the Public Service descriptions since they do not vary among the diverse public service versions/variants. All the events have a start and end time expressed through the "Time" concept.

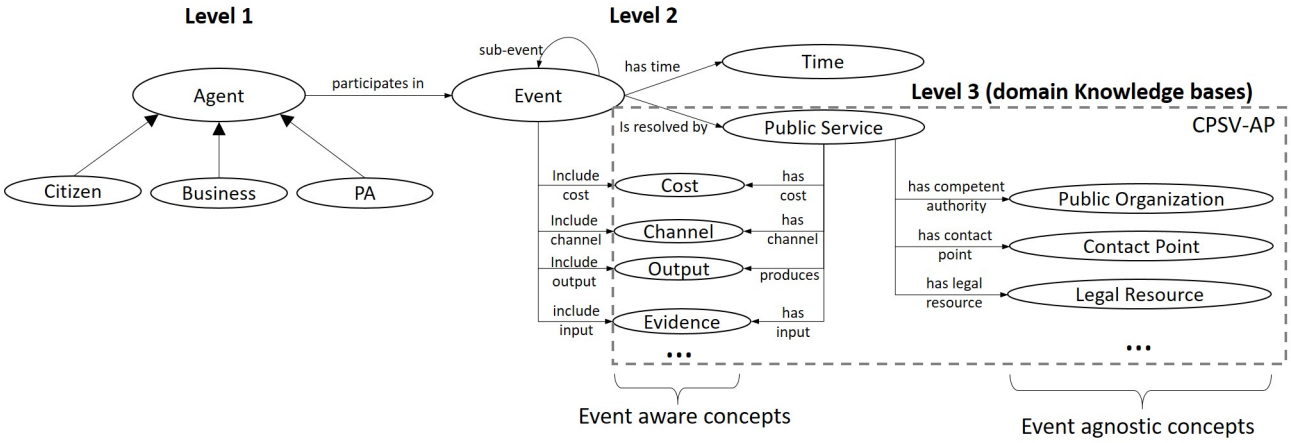

Figure 1. The proposed ECKG model for public administration.

The concepts of the proposed model can also be associated with other external PA domain knowledge bases (i.e., ontologies, taxonomies, and thesauri) in order to add more context information to the ECKG. For example, the proposed model can use existing PA knowledge bases, documented in the CPSV-AP specification [47], to retrieve information about life events, business events, channels, evidences, legal resources, etc.

4. Applying the Model: The Case of Greek Public Administration

This section applies the proposed ECKG model to the case of the Greek public administration. This case uses data from the Greek National Registry of Administrative Public Services (MITOS).

4.1. The Public Service Provision Landscape in Greece

MITOS (https://mitos.gov.gr/ (accessed on 25 December 2023)) is the official national registry of administrative public services in Greece and provides descriptions of almost 4000 public services, including information about their cost, available channels (physical, digital), required input, provided output, relevant legislation, competent authorities, relevant life events, etc. The data model underlying MITOS is compatible with CPSV-AP.

Most of the services have different variants based, e.g., on the beneficiary categories of the public service, the required input for the service, and the cost. For example, regarding the beneficiary categories, there are 20 different versions of the public service responsible for the postponement of conscription due to various beneficiary situations (health problems, social issues, current education, living abroad, etc.) and seven different versions of the public service responsible for granting financial aid to disabled people based on the type of disability (mental disability, vision impairment, deafness, physical disability, etc.). Regarding the input/cost, there are multiple versions of the public service responsible for issuing a passport since the required input evidence may vary from two up to twelve, since 10 pieces of evidence are conditionally required, e.g., if the applicant is not an adult, in case of previous passport loss, in case of emergency passport issuance due to health issues, etc., while the cost may vary from EUR 5 to 84.4, respectively.

The public services in MITOS are categorized based on life/business events and use/change data of various base registries. For example, the "birth" life event encompasses 28 public services (initial registration of a minor, birth allowance, issuing of birth certificate, naming a minor, etc.) that use/change data in seven base registries (e.g., citizen registry, registry of insured persons, electoral registry, allowances registry), while the "start of a new business" event encompasses 23 public services (e.g., issuing a tax registration

number, registration of the legal entity, obtaining a special permission for operating, e.g., a playground, etc.) that use/change data in various generic or business domain registries (tax registry, commercial registry, auditors registry, registry of shipping companies, registry of agricultural products, traders, etc.).

Additionally, MITOS categorizes public services based on broad categories of beneficiaries including citizens, public servants, public administrations, businesses, freelancers, and legal entities. These categories are aligned with the core PA entities of the proposed ECKG model.

The services described at MITOS are offered through various physical and digital channels. The most popular channel is the National Single Digital Gateway (gov.gr). It offers almost 1600 digital public services (https://www.secdigital.gov.gr/stats/ (accessed on 25 December 2023)), with 8 million distinct citizen-users and 200 million public service provisions during a two-year period (2020–2022). These provisions include, for example, 10 million solemn declarations, 1 million issuances of birth certificates, etc. Another popular channel is the Citizens' Service Centres (CSC) (https://www.kep.gov.gr/ (accessed on 25 December 2023)). CSCs are "one-stop-shops" established in 2002 and they aim to facilitate the interactions of citizens with the state. Recently, they have also been offering a digital/remote channel to serve people via video conference. Based on published statistical data (http://kepstats.mindigital.gr/ (accessed on 25 December 2023)), CSCs provide on average 8–9 million public services per year.

In summary, the public service provision landscape in Greece (i) includes many public services with multiple variants; thus, there is a need to track the specific variant used; (ii) uses data from various base registries; thus, a holistic data governance and integration approach is needed to enable continuous intelligence; (iii) encompasses a number of life/business events that occur and trigger the execution of more than 100 million public service instances per year. Such a complex and continuously evolving landscape can benefit from the use of the proposed ECKG approach in order to capture not just the resulting state of the public services but also dynamic information such as the events triggered and their surrounding context.

4.2. Case Study: Birth Life Event

This subsection presents a case based on MITOS where the proposed ECKG model can be applied. The "birth" life event in MITOS encompasses 28 public services. In the framework of this case, we will examine three of them: (i) the public service responsible for issuing a birth certificate, (ii) the public service responsible for granting a birth allowance, and (iii) the public service responsible for granting a monthly child allowance. The following paragraphs present short textual descriptions of these public services. Some "exceptional" characteristics of the public services (e.g., some optional input) are not included for simplicity. For example, the public service responsible for granting a birth allowance has 12 input evidences; however, for simplicity reasons we consider only six of them. The complete structured descriptions of the services are available in MITOS in the Greek language.

The public service responsible for issuing a birth certificate has as its competent authority the Ministry of the Interior; the service is offered through four different channels, namely, the physical offices of the Registry Office, the physical and online Citizens' Service Centres, and the National Single Digital Gateway (gov.gr); this service requires as input the ID card of the applicant and optionally an authorization in case the applicant is not the person for whom the birth certificate is requested.

The public service responsible for granting a birth allowance has as its competent authority the Ministry of Labor and Social Security; is offered through two different channels, namely, the physical offices responsible for granting the birth allowance and the National Single Digital Gateway (gov.gr); and requires as input the ID card of the applicant, an IBAN certificate declaring the bank account where the money will be deposited, optionally the Birth Certificate in case birth information cannot be retrieved automatically

from the relevant registry, optionally the Marital Status Certificate in case the parents are non-Greek citizens, optionally a Residence Permit in case the parents are non-EU citizens, and optionally a Notarial Deed for Child Recognition in case the child is not born to married parents. The allowance granted is EUR 2000 per child that is born in Greece, regardless of the parents' income.

The Public Service responsible for granting a monthly child allowance has as competent authority the Ministry Of Labor and Social Security; is offered only through the National Single Digital Gateway (gov.gr); requires as input optionally a Marital Status Certificate in case information cannot be retrieved automatically from the relevant registry, optionally a Study Certificate for children above 18 years old that are studying, optionally a Residence Permit in case the parents are non-EU citizens, and optionally a Disability Certificate in case the child has a disability, is above 18 years old, and is not studying. It should be noted that this public service requires only optional input since most information is expected to be collected automatically from relevant registries. The monthly allowance per child varies based on the annual income of the parents and can be EUR 28, 42, or 70.

Based on the above public service descriptions, it is obvious that each service has many variants that occur due to the various channels that offer the service, the different inputs required due to different citizen circumstances (e.g., non-Greek, non-EU citizens) or the different output produced (e.g., different amount of monthly child allowance). A service variant consists of a specific combination of the above (channel, input, output, etc.).

In order to apply the proposed ECKG model, the following scenario is considered "*Olivia has given birth to a child on 10 October 2023. Olivia is not yet married with the father of the child, thus he has provided a notarial deed for child recognition. After the birth, Olivia interacted with PA using three public services: (i) public service responsible for issuing a birth certificate, (ii) public service responsible for granting a birth allowance and (iii) public service responsible for granting a monthly child allowance. The public service for issuing the birth certificate was executed through the physical offices of the Registry Office providing only the mandatory evidence "ID card". The public service for granting a birth allowance was executed through gov.gr, providing the mandatory evidence (ID card and IBAN certificate) as well as a "Birth Certificate" (since required information could not be automatically retrieved from the the relevant registry) and a "Notarial Deed for Child Recognition". Finally, the public service for granting a monthly child allowance was executed through gov.gr providing no input (every information instance needed was collected automatically through the relevant registries) while the monthly child allowance is EUR 42 based on the parents income.*".

In order to implement the scenario, this paper uses the RDF/TTL (https://www.w3.org/TR/turtle/ (accessed on 25 December 2023)) representation. The first step for the implementation of the scenario is the mapping of classes/properties of the proposed ECKG model to existing models and vocabularies. The vocabularies used for the mapping are:

- The core vocabularies of the European Union (http://data.europa.eu/m8g (accessed on 25 December 2023)) (prefix `cv:`) which define concepts related to people (`cv:Person`), businesses, (`cv:LegalEntity`) and life events (`cv:LifeEvent`);
- The Core Public Service Vocabulary [47] (prefix `cpsv:`) of the European Union which defines concepts regarding public services (`cpsv:PublicService`) and their variations;
- The SEM vocabulary [18] (prefix `sem:`) which defines concepts related to events (`sem:Event, sem:hasSubEvent, sem:hasTimeStamp`.)

In cases where no relevant concepts can be found from the existing vocabularies, the paper defines new concepts (prefix `ex:`). For example, the participation of a citizen in a life event is modeled through the predicate `ex:participatesIn`. Additionally, the association of an event with a public service is modeled through the predicate `ex:isResolvedBy`, while all relations of `sem:Event` with the event-aware CPSV-AP concepts are also expressed through the `ex:` prefix i.e., `ex:includeChannel`, `ex:includeOutput` and `ex:includeInput`.

Listing 1 presents the RDF/TTL descriptions of the three public services of the case study using CPSV-AP. The descriptions include information about all the concepts related to a public service, e.g., all available channels or all possible inputs that could be used. It

should be noted that during the provision of the public service, only some of them will be used, e.g., only one channel. These descriptions should normally be part of a knowledge base of public services (e.g., a Linked Data version of MITOS) that contains all the public service information needed to add context to the ECKG. The existence of such a domain knowledge base is beneficial since it enables the use of unified terminology not only for the proposed ECKG but in general.

Listing 1. CPSV-AP-based RDF/TTL code of a public service knowledge base (partial).

```
ex:BirthCertificatePS a cpsv:PublicService;
cv:hasCompetentAuthority ex:MinistryOfInterior;
cv:hasChannel ex:RegistryOfficePhysical, ex:CSCphysical,
ex:Govgr,ex:CSConline;
cv:hasInput ex:IDcard, ex:Authorization;
cv:produces ex:BirthCertificate.

ex:BirthAllowancePS a cpsv:PublicService;
cv:hasCompetentAuthority ex:MinistryOfLaborAndSocialSecurity;
cv:hasChannel ex:BirthAllowancesPhysicalOffice, ex:Govgr;
cv:hasInput ex:BirthCertificate, ex:IDcard, ex:MaritalStatusCertificate,
ex:ResidencePermit, ex:NotarialDeedChildRecognition,
ex:IBANcertificate;
cpsv:produces "2000"^^xsd:integer.

ex:MonthlyChildAllowancePS a cpsv:PublicService;
cv:hasCompetentAuthority ex:MinistryOfLaborAndSocialSecurity;
cv:hasChannel ex:Govgr;
cv:hasInput ex:MaritalStatusCertificate, ex:StudyCertificate,
ex:ResidencePermit, ex:DisabilityCertificate;
cpsv:produces "28"^^xsd:integer, "42"^^xsd:integer, "70"^^xsd:integer.

ex:MinistryOfInterior a cv:PublicOrganisation.
ex:MinistryOfLaborAndSocialSecurity a cv:PublicOrganisation.
ex:RegistryOfficePhysical a cv:Channel.
ex:CSCphysical a cv:Channel.
ex:Govgr a cv:Channel.
ex:CSConline a cv:Channel.
ex:IDcard a cv:Evidence.
ex:Authorization a cv:Evidence.
ex:BirthCertificate a cv:Evidence, cv:Output.
ex:MaritalStatusCertificate a cv:Evidence.
ex:ResidencePermit a cv:Evidence.
ex:NotarialDeedChildRecognition a cv:Evidence.
ex:IBANcertificate a cv:Evidence.
ex:StudyCertificate a cv:Evidence.
ex:DisabilityCertificate a cv:Evidence.
```

Listing 2 presents the RDF/TTL code for the scenario. The code includes two levels of events. The first level is the life event “Birth" which is used in order to group a set of three public service provisions while the second includes the sub-events which capture information about the public service provisions. Each of the sub-events is associated with the public service knowledge base (Listing 1) using only the values of the CPSV-AP event-aware concepts that were actually used during the specific interaction. For example, the “Birth Certificate Public Service” has four potential channels (Listing 1) while the *ex:BirthCertificateEvent* is associated only with one of them, i.e., *ex:RegistryOfficePhysical*,which was actually used. An interesting remark is that both the life event and the sub-events have a time stamp; however, the time stamps differ. This occurs since the birth was on 10 October 2023 while the provision of the three public services followed in the following days.

Another interesting remark is that the `cv:LifeEvent` is associated with a type property (`dct:type`) which allows the linking to a controlled vocabulary about life events. For example, the statement `ex:birth dct:type ex:HavingAChild` associates the life event `ex:birth` to the type “Having a child". Such controlled vocabularies contain domain-specific information, making the data in the ECKG meaningful.

Listing 2. RDF/TTL code for the scenario using the proposed ECKG.

```
ex:Olivia a cv:Person;
ex:participatesIn ex:birth.

ex:birth a cv:LifeEvent;
sem:hasTimeStamp "2023-10-10T09:30:00"^^xsd:dateTime;
dct:type ex:HavingAChild;
sem:hasSubEvent ex:BirthCertificateEvent, ex:BirthAllowanceEvent,
ex:ChildAllowanceEvent.

ex:BirthCertificateEvent a sem:Event;
sem:hasTimeStamp "2023-10-12T12:30:00"^^xsd:dateTime;
ex:isResolvedBy ex:BirthCertificatePS;
ex:includeInput ex:IDcard;
ex:includeChannel ex:RegistryOfficePhysical.

ex:BirthAllowanceEvent a sem:Event;
sem:hasTimeStamp "2023-10-13T11:20:00"^^xsd:dateTime;
ex:isResolvedBy ex:BirthAllowancePS;
ex:includeChannel ex:Govgr;
ex:includeInput ex:BirthCertificate, ex:IDcard, ex:IBANcertificate,
ex:NotarialDeedChildRecognition ;
ex:includeOutput "2000"^^xsd:integer.

ex:ChildAllowanceEvent a sem:Event;
sem:hasTimeStamp "2023-10-30T11:20:00"^^xsd:dateTime;
ex:isResolvedBy ex:MonthlyChildAllowancePS;
ex:includeChannel ex:Govgr;
ex:includeOutput "42"^^xsd:integer.
```

4.3. Querying and Data Analytics

Based on the RDF/TTL representation of the public service knowledge base (Listing 1) and the scenario (Listing 2), a number of SPARQL queries can be executed highlighting the advantages of the proposed ECKG approach including data analytics.

Listing 3 presents a query that provides a comprehensive 360-degree-view of the core entity—citizen (i.e., Olivia), returning information about all the public services provided to Olivia over time, including information about the specific public service variant that was provided (input/output/channel). The retrieval of such information is very straightforward with a few lines of code. Such information can be beneficial to facilitate the personalization and proactive offering of public services. For example, this information can be used in order to propose "similar" public services to Olivia that she is not aware of (e.g., another type of child allowance of which she is a potential beneficiary) or personalize public services based on the previous public service provisions (e.g., required input specific to Olivia's situation).

Listing 3. A 360-degree-view of a citizen.

```
PREFIX ex: <http://www.exampe.org/>
PREFIX sem: <http://semanticweb.cs.vu.nl/2009/11/sem/>

select ?event, ?time, ?input, ?output, ?channel where {
<http://www.exampe.org/Alice> ex:faces ?le.
?le sem:hasSubEvent ?event.
?event sem:hasTimeStamp ?time.
?event ex:includeInput ?input.
?event ex:includeOutput ?output.
?event ex:includeChannel ?channel.
}
```

Listing 4 presents a query that provides a comprehensive 360-degree-view of a Public Organization (i.e., Ministry of Labor and Social Security), returning information about all public services provided by the Ministry of Labor and Social Security in 2022. This information is easily returned through a few lines of code and can facilitate the prediction

of future public service provisions and thus the planning of the Public Organization in terms of personnel or money resources. The returned result of the query, based on the data of the scenario, is presented in Figure 2.

Listing 4. A 360-degree-view of a Public Organization.

```
PREFIX ex: <http://www.exampe.org/>
PREFIX sem: <http://semanticweb.cs.vu.nl/2009/11/sem/>
PREFIX cv: <http://data.europa.eu/m8g/>

select  * where {
?event ex:isResolvedBy ?ps.
?ps cv:hasCompetentAuthority ex:MinistryOfLaborAndSocialSecurity.
?event sem:hasTimeStamp ?time.
FILTER(?time >='2022-01-01T00:00:00'^^xsd:dateTime &&
?time <'2023-01-01T00:00:00'^^xsd:dateTime)
}
```

event	ps	time
http://www.exampe.org/BirthAllowanceEvent	http://www.exampe.org/BirthAllowancePS	2023-10-13T11:20:00
http://www.exampe.org/ChildAllowanceEvent	http://www.exampe.org/MonthlyChildAllowancePS	2023-10-30T11:20:00

Figure 2. Result of SPARQL in Listing 4.

Listing 5 presents a query that returns the total amount of birth allowances granted to children born outside of marriage in 2022 through gov.gr. This query demonstrates the simplification of the queries and the easy integration of data from various DBs with a simple schema. This query requires information for various concepts, i.e., person, public service, channel, input and output, which in a relational DB would normally be stored in different tables. Additionally, a relational DB requires the use of intermediate tables, e.g., a table to capture the event information and a table to model the use of many inputs during public service provision. Thus, an equivalent SQL query will be much more complex and more demanding in terms of computational resources, since it requires the joining of at least seven tables. Based on this query, it also becomes obvious that an addition of a new concept (e.g., public service cost) or of a new event type (e.g., payments of citizens to the PA) can be modeled using the same ECKG model with minor changes, e.g., model the new event type, while the core of the ECKG model (Agent, Event, Time) will remain the same.

Listing 5. Total amount of birth allowances granted to children born outside of marriage in 2022 through gov.gr.

```
PREFIX ex: <http://www.exampe.org/>
PREFIX sem: <http://semanticweb.cs.vu.nl/2009/11/sem/>
PREFIX cv: <http://data.europa.eu/m8g/>

select  SUM(?allowance) where {
?event ex:isResolvedBy ex:BirthdAllowancePS.
?event ex:includeChannel ex:Govgr.
?event ex:includeInput ex:NotarialDeedChildRecognition.
?event  ex:includeOutput ?allowance.
?event sem:hasTimeStamp ?time.
FILTER(?time >='2022-01-01T00:00:00'^^xsd:dateTime &&
?time <'2023-01-01T00:00:00'^^xsd:dateTime)
}
```

Other queries can also be expressed, retrieving, for example, the total number of public service provisions per channel, the total number of public service provisions for a specific variant, e.g.,EUR 42 monthly child allowance, total amount of allowances granted to a specific citizen, etc.

5. Discussion

The results based on the application of the proposed ECKG model to the case of the Greek public administration indicate that the model can address the needs of event modeling in the domain of public administration. Specifically, the events in public administration are mainly related to the provision of public services while many public services with multiple variants may exist. The proposed ECKG model extends the existing cross-domain ECKG models (that include core concepts like the 'Agent', 'Event', and 'Time') by adding public administration-related concepts like the 'Public Service'. In this way, events can be associated with the provision of public services. Additionally, the modeling of public services is based on the CPSV-AP model, which however cannot handle different public service versions/variants efficiently (i.e., all versions are modeled under the same public service definition). The proposed ECKG model provides the mechanism to associate events with the specific public service version/variant that is provided while not duplicating any information of the CPSV-AP public service descriptions.

Another PA domain-specific need is the grouping of events to high-level events such as life/business events. The notion of life/business events is already recognized in the literature and is related to the grouping of public services in order to fulfill specific citizen needs. The proposed ECKG model considers these two levels of event grouping; thus, events can be either high-level (e.g., birth) or more fine-grained (e.g., birth registration), while the high-level life events may have one or more fine-grained sub-events. An interesting remark is that both the life event and the sub-events have a time stamp; however, these time stamps may differ. This occurs since the life event occurs at a specific time, while the provision of the relevant public services may follow in the forthcoming period.

The use case for the Greek public administration highlighted that the data produced and handled by public administrations are usually organized in various heterogeneous databases and base registries, hindering a comprehensive understanding of PA operations. Thus, a holistic data governance and integration approach is needed. The proposed ECKG model is simple and expressive enough to enable the integration of data from various databases and base registries. The current model can express various event types that are related to the provision of public services. However, if other types of events that cannot be expressed come up (e.g., payment of citizens' financial obligations), then the model can easily be extended by adding new event types. In this case, a new event type can be added just by introducing a new relevant concept and associating it with the Agent–Event–Time scheme, while all the other core concepts remain the same. Thus, the adoption of the model can be done progressively by the existing databases and base registries while the model can easily be fine-tuned if needed.

Another feature of the proposed ECKG model that also facilitates data integration is the inherent use of external domain knowledge bases. Such knowledge bases provide a unified terminology that can be applied when integrating or querying the data. A domain limitation that arises at this point is that the existing public administration knowledge bases are limited and thus their expansion would be beneficial not only for the proposed ECKG but in general.

The application of the model (Section 4.3) showcases the possibilities/advantages that arise from the adoption of an ECKG approach for data management in public administration. The tree structure of the proposed ECKG model facilitates a comprehensive 360-degree-view of Agents including citizens and public organizations. Such information can be beneficial to enable personalization of public services based on previous public service provisions, or for the proactive offering of public services to citizens based on "similar" public services. Additionally, the tree structure is also expected to improve the performance of querying since the events in public administration involve only a few core Agents (citizen, business) which are positioned at the root of the tree structure. In this way, the root acts as an "index" of the events. So, queries that require the events per Agent are facilitated.

The simple structure of the proposed ECKG, as well as the inherent use of the time dimension, also facilitate the use of data analytics by simplifying querying and feature extraction, e.g., presenting Agents (e.g., citizen, public organization) as a series of events. This in turn enables time series analysis for event prediction and for the identification of next best actions. For example, this includes, among others: (i) the prediction of future interactions of citizens with PA, enabling resource (i.e., personnel, money) planning for public organizations, e.g., reserving the appropriate amount of money to be given through allowances, and (ii) the prediction of the public service version/variant to be consumed in each interaction, enabling, e.g., management of the channels offering the service.

The possibilities presented above highlight the potential of the proposed ECKG approach and the benefits it can bring to public administration. The capabilities of the proposed approach still remain to be tested at large scale using real big data from public administration.

6. Conclusions

In a continuously evolving environment, public administrations need to quickly adapt to change and make decisions in real-time while having a real-time understanding of their context. This requires adopting an event-native mindset [1]. Towards this direction, this paper proposes an event-centric knowledge graph approach and model for the holistic data governance of all data repositories in PA, which models all interactions amongst PA-related actors. The adoption of the proposed model can be a first step towards a broader event-native mindset in PA since it uses events as first-class entities in data management.

A set of models and approaches have already been proposed in the literature in order to represent events and their context. However, these models are cross-domain and do not capture the specific needs of PA. For example, they do not consider events (i.e., interactions with a public service) and their versions in the context of PA or do not define the Agents that interact with the PA. The proposed ECKG model for public administration is based on: (i) a state-of-the-art analysis of existing ECKG models in order to identify core concepts related to event modeling, (ii) a state-of-the-art analysis of existing public administration models and ontologies in order to identify core domain entities related to event modeling, and (iii) a theoretical analysis of concepts related to events, public services, and effective public administration in order to outline the context and identify the domain needs of event modeling.

The proposed model uses CPSV-AP to describe public services and their versions. Thus, the model relies on CPSV-AP to express any complexity related to public services, e.g., the expression of hierarchies and internal structure of public organizations, contact points, and legal resources. However, CPSV-AP cannot handle public service versions/variants efficiently; thus, the proposed ECKG model provides a relevant mechanism to associate events with the specific public service version/variant provided.

The results from the application of the proposed ECKG model to the case of the Greek public administration showed that the model is capable of capturing the complexity of the domain which comprises many public services with multiple variants, uses data from various base registries, and encompasses a number of life/business events that occur and trigger the execution of many public services. Additionally, the results showed that the adoption of event-centric knowledge graph approaches for data management in public administration can facilitate data analytics, continuous integration, and the provision of a 360-degree-view of end-users. We anticipate that the proposed approach will also facilitate real-time decision-making, continuous intelligence, and ubiquitous AI.

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