A Domain Model for the IST Infrastructure

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Abstract. A model driven engineering (MDE) approach is positioned w.r.t. collaborations of multiple agents acquiring information society technology (IST) capabilities. Our focus is on the stakeholders of work systems, their adaptive cycles, and their aligned assets, computation independent models in particular. When referring to the state-of-the-art in the software application interoperability area, three "missing" fragments of the domain model for the IST Infrastructure are explored: a *Total Asset Methodology* (TAM), an *Extended Generic Activity Model* (EGAM), and a concept for *TOken-based eXecution In Knowledge Spaces* (TOXIKS).

1 Introduction

This paper positions a model driven approach in the context of cultural historical activity theory [20] and IT-reliant work systems [4]. It considers society, enterprises and persons as goal-oriented agents that acquire IT capability (also called IST instruments or IST infrastructure)[11]. Earlier preliminary results on architecture descriptions for an information infrastructure[12] are extended. Relevant state of the art is vast and a systematic recollection does not fit in the available pages for this paper. Interested readers are referred to INTEROP state of the art reports, or to the listed references. Focus in this paper is on fragments in the domain model that complement the current Model Driven Engineering "received view" and its modelling foundation. Particular focus is on the early phases of IST instrument acquisition in IT-reliant work systems. Total Asset Methodology (TAM) and Extended Generic Activity Model (EGAM) have a focus on generic requirements, for society and its members. The TOken-based eXecution In Knowledge Spaces (TOXIKS) execution concept has a focus on how TAM and EGAM can deliver.

2 Goal-oriented Agents, IST Instruments and Infrastructure

An IST infrastructure consists of the information models, data, and information processing services and tools that are shared by the different autonomous agents that collaborate or interact in a community or society. The trend towards an ubiquitous information infrastructure builds on the connectivity and low-cost high-performance computing and communication facilities provided by computers, the Internet and wireless communications, ranging from Bluetooth to satellite-based. An IST infrastructure is defined for and embedded in a society to support (all) the society's members and communities.

The term *society* has the meaning of "all people, collectively, regarded as constituting a community of related, interdependent individuals". A *community* is "a group of people having interests or work in common, and forming a smaller (social) unit within a larger one." This definition thus covers enterprises, public bodies, municipalities, nations, sports clubs, schools, hospitals, etc. All members of the society are *persons* with equal rights. Each person may belong to several communities. A community has no member outside society.

An ubiquitous IST infrastructure will support interactions that involve at least three kinds of agents and their IST instruments. At each level, one can apply the concepts of the IT-reliant work system.

Humans or micro-agents use personal IST instruments. Their win conditions include a.o. empowerment, legal security, efficient operations, optimal propagation of change, minimal inconsistencies, data protection and privacy[6].

Meso-agents such as businesses, universities, public bodies or any other kind of organisation, have mission-oriented IST instruments. Their success depends on the support that its members receive for their relevant actions, conform the processes or collaborations that have been enacted within it, conform the society's law or rules. E.g., the certification of a new type airplane by the relevant authorities, or the carrying out of tax payments and elections. Change must happen smoothly, without disrupting the community's processes, and with a minimal burden to its members.

Society, the (socio-industrial) eco-system in which micro-agents and meso-agents exist, has an IST infrastructure to share information, publicly, for certain missions, or in the context of contracts. The society as a whole pursues compliance to its enacted institutions and agreed upon policy goals (e.g. fair trade and protection of property in the global society). It could have goals such as rapid implementation of new "rules" or charters and it could use the subsidiarity principle to organize its institutions and ensure that each problem is addressed at the level at which it is common for all the lower-level stakeholders.

Each pair of agent and instrument has become a "software/data/knowledge intensive system" for which the standard IEEE 1471-2000[13] defines architecture.

Typically, each agent will deploy applications serving its interests. Maybury for instance, describes Collaborative Virtual Environments for distributed analysis and collaborative planning for intelligence and defense[16]. The DIISM conferences have been dedicated to the design of the information infrastructure systems for manufacturing and engineering enterprises[5]. Virtual communities in relation to Peer-to-Peer collaboration architectures are discussed in[15].

Section 3 proposes a synthetic change framework and adapted modelling primitives. Section 4 addresses missing fragments of the domain model for the IST Infrastructure.

3 Anchoring IST Instrument Acquisition by Models

The current state of the IST infrastructure is that physical view aspects of its architecture are better understood than the conceptual view aspects. A crisp problem statement can be found in DODAF [10,page 3-1]: *Requirements were often developed, validated, and approved as stand-alone solutions to counter those specific threats or scenarios, not as participating elements in an overarching system of systems. This approach fosters an environment in which DoD Components make acquisition decisions that, in a joint context are not fully informed by, or coordinated with other components. ..acquisition pipeline that is inefficient, time consuming, and does not support interoperability ...Additionally, acquisition management focuses solely on materiel solutions and does not adequately or fully consider the profound implications that changes in joint Doctrine, Organization, Training, Leadership & education, Personnel, and Facilities (DOTMLPF) may hold for the advancement of joint warfighting*." This statement points at the broad-scope context in which interoperability problems emerge. Anchoring the IST instrument acquisitions w.r.t. available assets, including the goals, needs, domain models and context of work of the acquiring agents, is one of the drivers for the Total Asset Methodology (TAM). The TAM promise is that acquisition decisions can prevent the emergence of semantic interoperability problems, thus limiting the need for curative approaches [18] to legacy systems. The OMG-proposed Model Driven Architecture (MDA) puts the model, a specification of the system functionality, on the critical path of software development, prior to the implementation of that functionality on a specific technology platform. Beyond OMG-MDA, TAM aims for an end-to-end role of computation independent domain models in the re-engineering of work systems and the acquisition of IST instruments.

3.1 Computation Independent Models in Work System Change Projects

Intuitively, the vision of model driven engineering can be linked to a combination of Boehm's Win-win Spiral model [7] and Kruchten's 4+1 view model [14] of (software) systems architecture. This combination proved effective in several change projects in companies. The collaborative foundation of the Win-win spiral ensures that the end-users drive the IT capability acquisition. The model also introduces milestones to anchor the acquisition process, and to assess and mitigate risks. The 4+1 view model is adopted because the re-engineering of IT-reliant work systems are situated in an engineering context where a large portion of specifications (expressed as models), software systems and data, and hardware systems are (re-)used and/or have to inter-operate (in a software intensive system), and evolve over time.

For the specification of the domain of IT-reliant work systems we introduce *Activity Patterns* as a modelling formalism. It has traits of High Level Petri nets but adopts the concepts of Cultural Historical Activity Theory. UML Class diagrams are used for *entity modelling*. All models in the conceptual view are computational independent models (CIM) in the sense of MDA. The platform specific models (PSM) are part of the physical view.

Assume now that there is an existing work system (AS-IS) with identified stakeholder needs. Then the re-engineering spiral in Figure 1 is model enabled: stakeholder needs are identified, analysis and design phases deliver an extended or new system specification, often with refinements in the logical view and the activity patterns. Development and implementation deliver the TO-BE physical realization meeting the identified needs. The logical view models, activity patterns and system specifications are soft assets, maintained and available for future change projects.

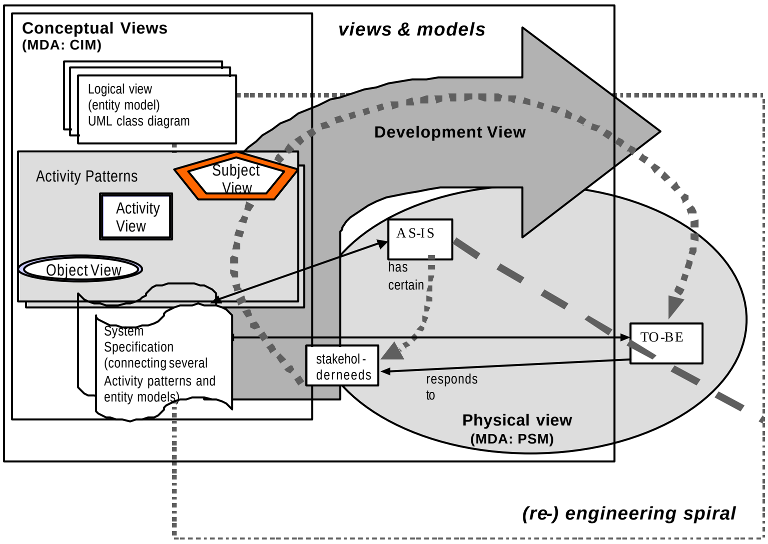

Fig. 1. A re-engineering spiral anchored by views and models

3.2 Introducing Activity Patterns

Cultural-Historical Activity Theory (CHAT) is suitable to perform contextual analysis for cognitive processes in which the cognition is embedded in broader institutional structures and long-term historical trajectories of development and change[20]. Concepts and tools that the society has developed during its history culturally mediate interactions of the human in the world. For analyzing an *activity*, we must consider its *subject*, the entity performing the activity, and its *object*, the necessary entity that allows realizing the outcome. A tool can be anything used in the transformation process, including both material tools and cultural mediators. The cultural mediators or artifacts that individuals (subjects) use also carry the typical intentions and objectives of people in specific situations. CHAT regards enterprise and society development as a process of remediation: the substitution of old mediating artifacts (for instance sentences on papers and in documents) with new artifacts (including the IST instruments), which better serve the needs of the activity concerned. Remediation means that the external objects are seen in a new context.

Drawing on the CHAT conceptual framework the Activity Pattern modelling formalism articulates three primitive building blocks: the *activity block* (rectangular), the *object block* (oval) and the *subject block* (pentagonal). Between blocks of the same kind, the arc (+) denotes a *sub-block* relationship (e.g., a sub-object is part of an object). An arc associating an activity block to an object block denotes an *involvement* (of the object in the activity). Directed arcs may be used to express that an object is the output or the input of an activity. An arc associating a subject block to an activity block denotes a *participates* relationship (active involvement, the subject performs the activity). A subject structure consisting of a hierarchical structure with several subject blocks, can be used to describe an organisational structure: in this case the subject blocks represent organisational elements or units. An activity structure (a hierarchical structure with several activity blocks) corresponds to a work break down structure. A product structure can be represented as an object structure (a hierarchical structure with several object blocks). Activities can take objects as input and produce outputs. For activities, the distinction between reliance on assets (stock) and the consumption or production of objects (flow) is represented by connecting the arc to a different side of the rectangle: left or right side for flow; bottom side for reliance on assets. Subject blocks are linked to the topside to express participation in the activity. In this paper we do not address the allocation of activities to subjects.

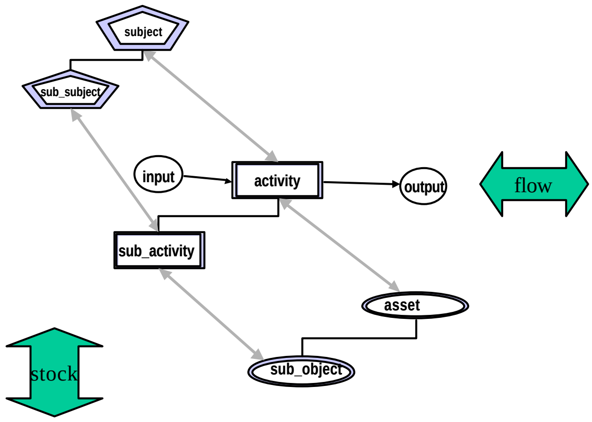

Fig. 2. The building blocks and arcs of Activity Patterns

A first characteristic of the activity pattern is its generic aspect: all blocks are *open*, and can be refined at any time. For a given work system, multiple activity patterns must be specified. The transitions of asset tokens (e.g., a databases) or moves of flow token (e.g., a cases) are synthesized from the specifications of multiple activity patterns. While the Activity Pattern has similarities with many other models, its distinguishing features include symmetric treatment of object, activity and subject, compositional properties that reflect epistemic pluralism, and a decoupled token based execution concept explained later in the paper. In what follows we liberally build upon the semantic constructs of Colored Petri nets to explain TOXIKS.

4 Total Asset Methodology for the IT-reliant Society

To explain TAM for IT-reliant agents in an information society we use GERA phases (Generic Enterprise Reference Architecture, Annex A to ISO 15704) to describe the agent's adaptive cycle. Regarding the model enabled aspect of TAM, we use the OMG MDA terms. After briefly introducing relevant elements from these frameworks, two specific themes are highlighted to illustrate the value-focussed flexible inter-operation of agents: (i) EGAM as a decisional reference model that emphasizes the frequent need for change in the work systems, and (ii) TOXIKS as an execution concept that reconciles stability in operations with dynamism in the knowledge spaces.

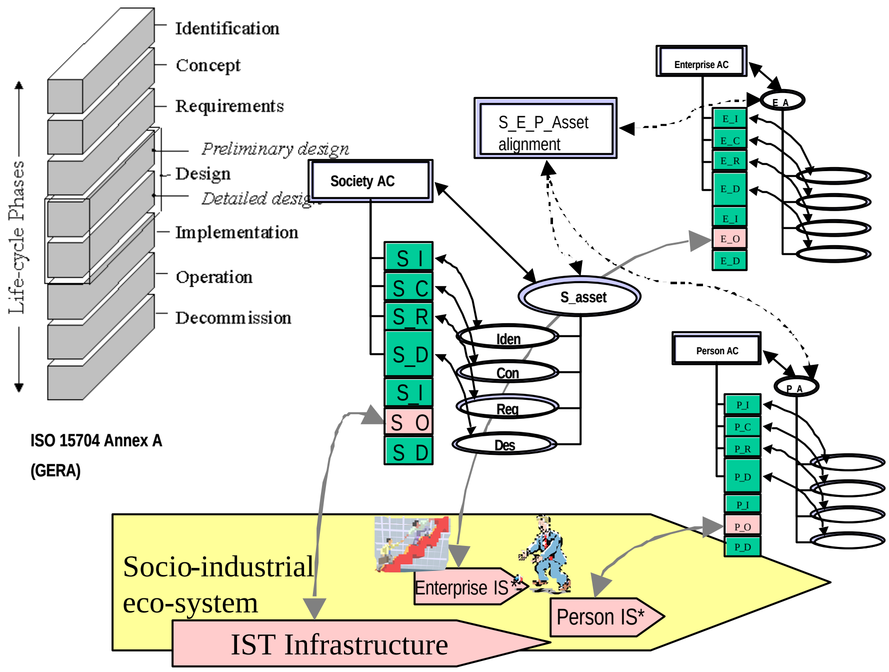

Fig. 3. GERA phases, assets and IST instruments for society and its members

4.1 Asset Alignment in the IT-reliant Society

The GERA phases (ISO FDIS 15704 - Annex A GERA) are used to distinguish the phases in the adaptive cycles in which the S-, E, and P-agents cope with new necessities. It is convenient to introduce S-GERA, E-GERA and P-GERA phases and name them: S-identification (S_I: Identification for Societal level), E-identification (E_I: Identification for Enterprise level) and P-identification (P_I: Identification for Person level), etc. The asset alignment activity is indicated for the objects supporting the respective GERA phases. All GERA phases for the society, enterprise and person agents may be ongoing. Each phase maintains specific assets to produce its outcome.

The activity patterns in Figure 3 are in the Conceptual View of Figure 1. The arrows in the lower part of Figure 3 give an abstract picture of the socio-industrial eco-system, its members and their IST instruments in the Physical View. The observed meso-agent variety in society is in the physical view. It is a result of "close-to-biological" evolution as comprehensively described by McCarthy et al. [17].

For any goal-oriented agent, the adaptive cycle is overseen by a planning process. Russell Ackoff defines planning as "*a process that involves making and evaluating each of a set of interrelated decisions before action is required, in a situation in which it is believed that unless action is taken a desired future is not likely to* *occur, and that, if appropriate action is taken, the likelihood of a favourable outcome can be increased*" [2].

4.2 TAM for IT-reliant work systems: Model Driven Engineering

The adaptation of IT-reliant work systems faces two huge hurdles[11]: socio-diversity and techno-diversity. To illustrate these hurdles, consider the society goal of reducing greenhouse gas emissions. The diversity at the operational layer is evident: gasses are emitted in a myriad of different situations. The people and businesses that are within the scope of any measure use multiple technologies and (software) solutions. This complicates the enactment of measurement and trading schemes such as proposed in Kyoto Protocol implementation schemes.

For overcoming similar hurdles, businesses have made explicit (externalised) their structure and operating procedures, especially with a focus on computer support for improved operations. These trends have already given rise to the large-scale use of enterprise models and the use of several dimensions to manage the complexity of enterprises applying ICT [3]. Enterprise Architecture tools are gaining importance in the market, and focussed architectural frameworks are being developed [10].

In the TAM road towards a knowledge society, the model and data assets will play a key role in designing and implementing policy measures in a calm manner, in accordance with the relevant legal principles, and for the available technology. As consolidated models are (becoming) available for the socio-technical contexts of work, any adaptive cycle (project) will deliver a "delta-specification" to realize a particular new scenario in a given socio-technical context. For a given subject (S, E or P) and its work system, the models at the three MDE layers (computation independent, platform independent and platform specific) result from different GERA phases, and are part of different asset layers. In the planning perspective each asset layer offers its own contribution to the reduction of risks[9] and to the system design. The Computation Independent Model (CIM) shows the system in the environment in which it will operate, and thus helps in presenting exactly what the system is expected to do (Concept). It is useful as an aid to understanding a problem and for communication with the stakeholders, it is essential to mitigate the risks of addressing the wrong problem, or disregarding needs. The use of platform independent and platform specific models (PIM and PSM) mainly matter when IST instruments are part of the solution.

4.3 A Decisional Reference Model

The model driven engineering (MDE) has no internal mechanism to identify problems in the work system. For the goal driven agent, IST instrument acquisition should be problem driven and asset enabled. In general, a problem refers to a situation, condition, or issue that is unresolved or undesired. In *society*, a problem can refer to particular social issues, which if solved would yield social benefits, such as increased harmony or productivity, and conversely diminished hostility and disruption. In *business* a problem is a difference between actual conditions and those that are required or desired. We assume that the values held by society are related to the so-called livelihood[1] assets: *human, natural, physical, social* assets in addition to *financial* assets. Given an indicator system, performance objectives are expressed and evaluated for a work system (object system) that performs a function. The environment is the source of inputs and the sink (market) for the outputs. The model in Figure 4 is called an *Extended Generic Activity Model* (EGAM) because it also includes the reflective activities that influence the operations of an object system. The governance activity, the management activity and the analysis&design activity support reflective functions of determining/setting the artefacts (objectives, problem, etc.) linked from their right-hand side. A quantitative difference between objectives and performance data signals a problem to the management activity. In pull-based change, the management activity will call upon the analysis&design activity to analyse the problem of the object system, to create new designs (TO_BE model & technology), and to compare performance. Governance and management activities decide about the implementation and acquisition of new capability proposed by the analysis and design activity in a management or governance advice (m_advice or g_advice).

In particular, the activities are defined as follows:

- The *object-system operation*: The operational processes that are performed by the object system, and for which performance *objectives* are expressed and evaluated,
- The *environment processes*: The processes of the environment in which the object system operates or performs a function – the environment is the source of *inputs* and the sink (market) for the *outputs*. Also *resources* originate from the environment, and *wastes* are deposited there (not in the figure),
- The *governance activity*: The activity in which objectives (stylistic and performance) are expressed for the object system, taking into consideration relevant constraints (natural, social, etc.) that exist for the capital assets in the factory's environment, it gives a mandate to the management activity.
- The *management activity*: The activity in which the operations of the object system are monitored and controlled. If one or more performance targets are not met, a problem is signalled to the analysis & design activity,
- The *design and analysis activity*: In this activity, performance problems of the object system are analysed, redesigns performed and evaluated, and advices given to the management or governance activity deciding which solution to adopt.

[1] Your livelihood is the job or other source of income which gives you the money to buy things that you need in your daily life. (Collins Cobuild English Language Dictionary). Means of living or of supporting life; subsistence (Webster's New World Dictionary.)

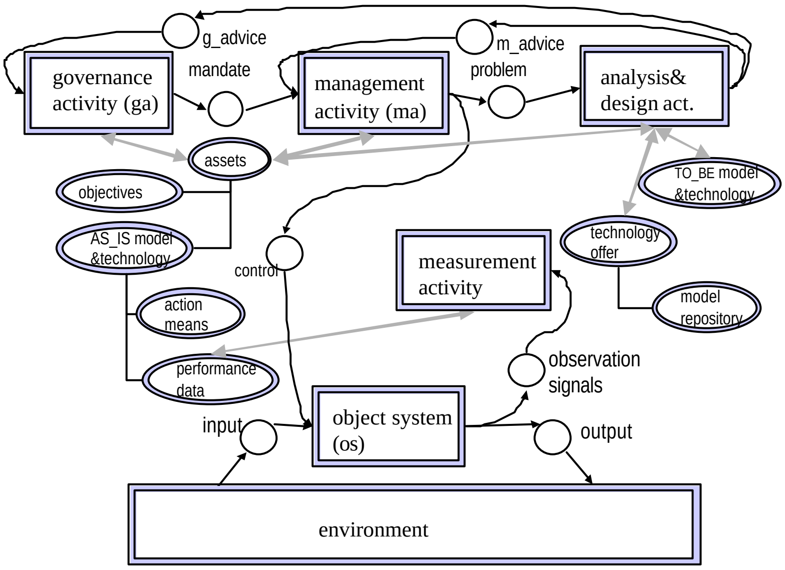

Fig. 4. The Extended Generic Activity Model (EGAM)

4.4 Token based Execution in Knowledge Spaces (TOXIKS)

Work systems must be adaptive to survive. EGAM draws one possible picture of the adaptive cycle. GERA draws another one. In the vision of TAM, multiple models and data must be reused. These models must also evolve. How can work system operations be liberated from the tyranny of the models in systems modelling? This question generalizes the question on instances and classes asked by Parsons and Wand[19]. TOXIKS is a tentative answer that draws on Bunge's distinction between ontology and epistemology[8] and generalizes the emancipating guidelines of Parsons and Wand. In essence, the token or instance is seen as an ontological construct, and the activity pattern or class as an epistemic entity. Such interpretations are generalized to transitions (actions, as instances of "class-like" activities), and to subjects (actors or agents as instances of subject-classes). A *Knowledge Space* is composed of some domain models (in UML), some activity patterns, and system specifications that specify transitions and related token classes over the activity patterns and the domain models (as in Colored Petri nets). Hence, a knowledge space is an epistemic construct. It usually is shared within an enterprise, a community, a science discipline, or culture.

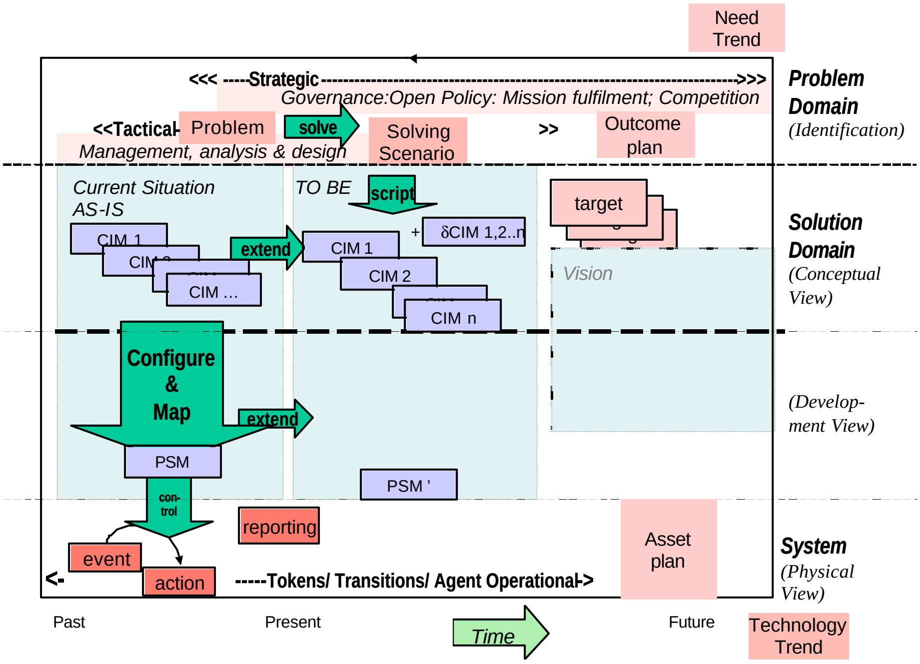

Fig. 5. Operations under Changing Knowledge Spaces.

A Knowledge Space is expressed as a CIM model, and defines meanings for operations and tokens as sketched in Figure 5. The knowledge spaces allows epistemic pluralism: multiple knowledge spaces coexist for a single object of analysis or discourse. Events in the work system are interpreted differently in the knowledge spaces pertaining to business (management), the workers, and societal monitoring systems, a.o. The workflow or work system operations (system row) is token based and has an ontological status. The token game is relatively stable and bound by laws in the hosting ontological stratum[1]. In contrast the knowledge spaces are highly adaptable, expandable and even dispensable for the operations. Their purpose lies in planning, though.

The development of the knowledge spaces is "driven" by the adaptive cycle initiated in a management or governance activity: a problem is identified. As part of an advice, the analysis&design activity proposes a scenario that solves the problem (pull style) or explains a promise (push style). The execution of the IT-reliant agent's MDE-GERA phases inludes the scripting of scenario's by specifying δCIM models w.r.t. the consolidated reference CIM models and by selecting suitable knowledge spaces (CIM'=CIM+δCIM); the δCIM is mapped to δPSM models; the δPSM models are included in the action prescriptions that will control the event flow and support the reporting demands. For instance, if there is a need for additional (new) measurements of ongoing event streams (ontologically, the same work system operations or primary process), then the measurements are defined as *d-actions* for selected events. Information about these events is recorded in accordance with the (new) interpretative structures (knowledge spaces, epistemic commitments) defined in δCIM and mapped to δPSM.

5 Conclusion and Future Work

This paper has proposed consistent fragments of the computation independent models of the domain that goal-oriented agents and their IT-reliant work systems share. The proposed models may evolve into assets in an IST infrastructure. A Total Asset Methodology (TAM), an Extended Generic Activity Model (EGAM) and an execution concept (TOXIKS) have been proposed. TOXIKS reconciles ontological invariance with epistemic pluralism and dynamism, and thus is a necessary feature of TAM at work. The validity of the proposed models and concepts must be further demonstrated. MDE-GERA style planning and development processes must be performed with aligned assets, multiple scenario's must be scripted with respect to these assets, and TOXIKS must be tested in IT-reliant work systems.

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