Enterprise Modelling
COMP 638

Assignment 3

Case Study

Naqi U Khan
Mickael Yusufidis

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Contents

Preface

This case study is created to satisfy the group study requirement for assignment 3 in COMP 638 Enterprise Modelling Winter 2019 course. It consist of one real world case description with one development model.

Digital Twin for Smart Cities

Abstract

With rapid advancements in technology, business systems are becoming more reliant on continuous intelligence to increase the probability of success and optimization. Adoption of virtualization and connectivity features of IoT (Internet of Things) by cities is on the rise to address local issues their residents face as well as to achieve meaningful outcome with data and connected technology. All of this comes with a cost of administering and managing a complex network of connected technology. In this study, we use high-level case examples to explain the creation and architecture of a digital twin as a system solution concept.

Introduction

Versatility of connectable technology IoT (Internet of Things) is opening new doors for the ease and comfort on many horizons. Cities are adopting this idea at higher than normal pace and embarking on smart city projects to replace their legacy systems with this robust and advanced technology. Because smart city is a huge network of IoT, large number of integrations points between IoT system components drives complexity into the development, testing, deployment and support of the systems. To meet this type of demand, digital twin is developed to meet the complexity limitations and allow the remote edge of endpoints participation in IoT lab or QA testing.

This paper aims to posit creation of a digital twin from scratch, from the beginning, proposed process and architecture included, developed using a design thinking fueled approach to spark innovation in the space of smart cities, suggesting the digital twin as a next generation progressive cybernetics and smart city (abstract) modelling technique.

Digital Transformation and The Sharing Economy

Digital Transformation

With the rise of interconnected technology, transformation of resources is inevitable. By adding more processing power, compact hardware and advancement in communications technologies, it is imperative for digital transformation to occur and dominate various essential aspects of today’s life.

Designers and manufacturers that can achieve digital excellence will thrive in this new world. To do so, they must create a consistent digital information thread throughout the enterprise and value chain. This founding principle is enabled and enhanced by cloud-and edge-based technologies and capabilities that can facilitate potential for gains in engineering, supply chain, manufacturing, final assembly and test. The digital twin is strategy that can turn this digital information thread into real value. [1]

The Sharing Economy

And there-in lies the resulting magic of digital transformation, a catalyst for the metamorphosis of digital commerce into a sharing economy. A sharing economy framework published by the Government of Ontario [2], clearly describes aligned principles with that of a smart city and digital twin alike, the economy's purpose, "to drive economic growth and innovation … an umbrella term that describes a wide range of economic activities that have been made possible by … technology … and digital platforms." Its technology driven guiding principles aim to [2]

- enable connections
- foster democratic participation in innovation and digital business,
- reduction of regulatory burden on businesses and citizens

More importantly, the framework's proposed plan of action couples "Collaborate and take action," [2] as a clear statement that pooling of objectives and resources is a philosopher's stone sharing economy goal, one that the concept of a digital twin, lends itself well to.

Smart City

Smart Cities, as a concept once called a future cities, can be traced back to the conception of wired cities [3] in the 1980s, and digital cities [4] in the early 1990s, followed by the smart growth movement [5]. Smart City is defined as a concept in many ways but a general explanation involves implementation and deployment of information and communication technology infrastructures to support social and urban growth through improving the economy, citizens' involvement and governmental efficiency [6]. It is an urban area that uses different types of electronic data collection sensors to supply information that is used to manage assets and resources efficiently [7].

Sample of Smart City idea taken from [8]

Barcelona is considered as a success story in urban development across Europe. Its objective was to use ICT in order to transform the business process of public administration internally and externally to be more accessible, efficient like boosting cooperation between the council, civil stratum and the professional arena, effective and transparent [9].

To transform itself into a Smart City, Barcelona has undertaken significant reforms that dates back to 1980. It changed from being in a deep economic crisis and having a serious infrastructure deficit, to becoming a leading metropolis [10]

The main components of the smart city of Barcelona were to create [9]:

- Smart districts to be able to create relationships between the city council and organisations.

- Living Labs initiative to be used as tools and processes for the creation of user innovation cooperatively in real-life environments.

- Redesigned its traditional infrastructure to ease the integration of ICT at all levels.

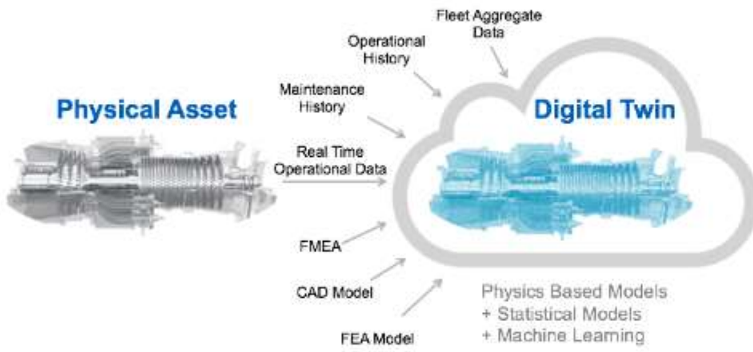
- New services for the citizen by making public worker's task easier so they can provide useful information to city managers that can result in better management decisions and evaluate policies.

- Open data initiative to [11] :
    (1) design and validate a network management platform and sensor data that can become a reference for other cities,
    (2) create a communications network of sensors that allows communication between many of the sensors developed across Catalonia,
    (3) identify a framework based on open standards,
    (4) develop a platform that is completely applicable for any city of any size and
    (5) explore and implement the appropriate services for public management enhancement

Today, transformation of Barcelona into a Smart City is continuing productively and it is already widely known as a leading city in Smart City initiatives all over Europe.

Digital Twin

Digital Twin is a comprehensive physical and functional description of a component, product or system, it consist of more or less all information that could be useful in current and subsequent lifecycle phases. [12]



Example of DT [13]

In order to validate systems properties, optimize operations and failure predictions, modeling and simulation in system development are generated that are later merged for physical solutions. This process allows easy handling of any complex system such as smart city for ease of use operations/maintenance, development / testing etc., brining unforeseen efficiencies to operational effort and capital/operational expenditures. "The Rise of the Sharing City" [14] implies via four city use cases initiative alignment opportunities in socio-economic domains such as:

- Transportation
- Food
- Housing
- Jobs and Skills

Furthermore, all of the cities shared similar challenges regardless of their background; with more liberal cities like Berlin and San Francisco leading culturally towards "sharing initiatives" that are ICT driven, replacing the economic layer with a dynamic technology layer meant to manage and interact with the crowd. More importantly, the observation that sharing can take on two broad streams of Research vs Development opportunities is important as well. Some development and predictive analysis will require privacy controls, especially where demographic information is heavily used; vs. sensory data (only). Sensory data will lend itself easier to sharing initiatives with research driven narratives. [14]

An example of development that lends itself to creating research narratives is the "Smart City Digital Twins" [16] case study, it involves developing a digital twin of Atlanta with a goal to immerse a human being into a virtual representation (digital) of Atlanta, using a VR interface, and measure human sensory interaction with a digital representation of a physical entity, again, the City of Atlanta. This case inspired the conceptualization of a digital twin creation process and system architecture described below.

Digital Twin Creation Process

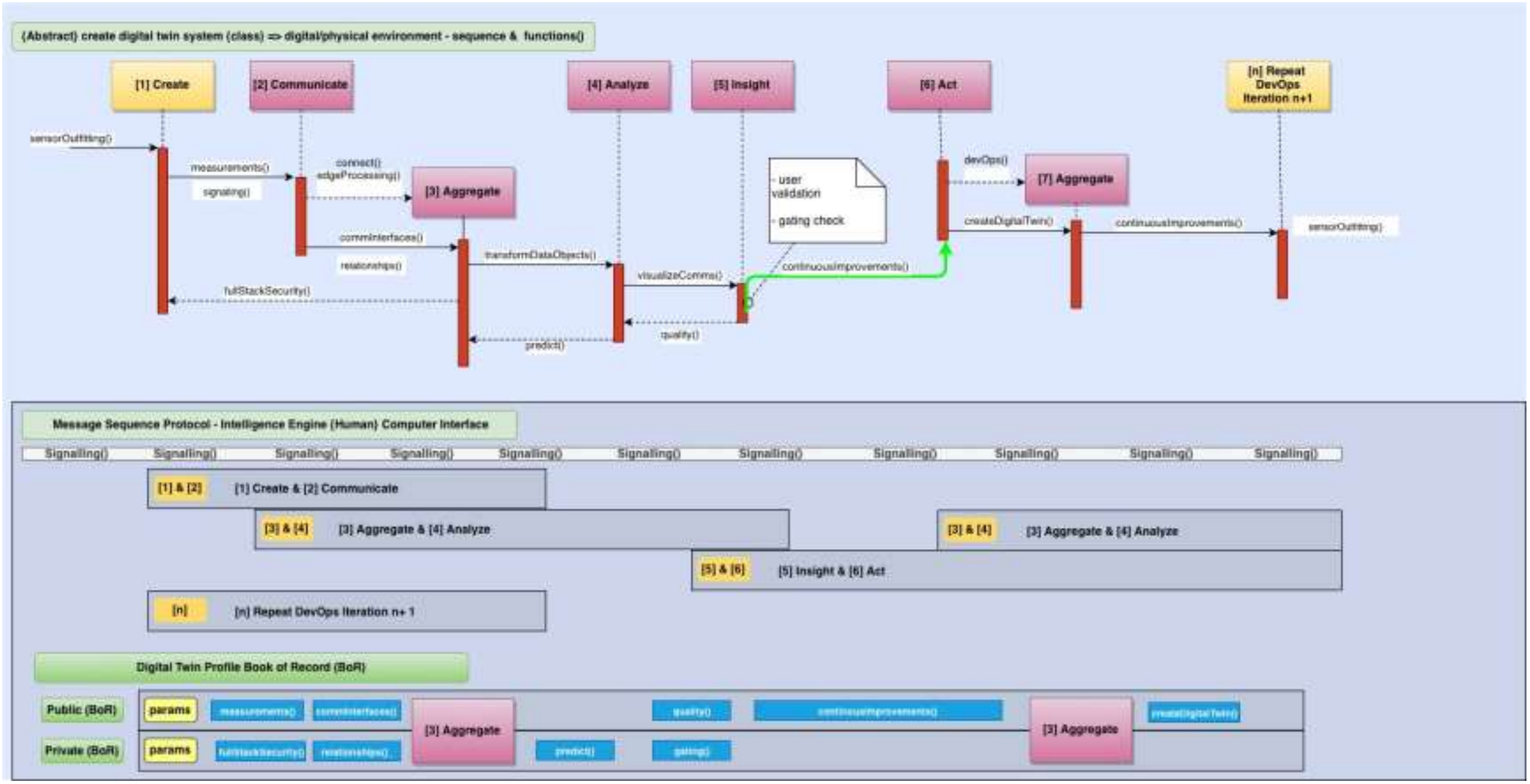
The Digital Twin creation process is well described within a white paper offered by Deloitte University [15]. The representation below is an abstract adaptation of the aforementioned context with an accompanying UML Sequence Diagram; inspired by a case study of creating a digital smart city twin conducted in Atlanta, GA. USA [16]; introducing a

- *“Smart City Digital Twin paradigm that can enable increased visibility into cities’ human-infrastructure technology interactions, in which spatiotemporal fluctuations of the city are integrated into an analytics platform at the real-time intersection of reality-virtuality.”* [16]

A sequence diagram was chosen because its ideal to model interactions of process and technology patterns in one storyboard. Process steps can also be abstracted as Class objects with functions. Some liberties in modelling expression were applied, including simplification and use of BPMN inspired notation to describe a protocol for typical message sequencing and info/data management between Classes, functions and a book of record (BoR), affording significant liberty for technology system design elaboration. In effect, it provides guidance on how to abstract a model, of any digital twin (treated as an object), from process and technology, insinuating business process driven object modelling. The visual presentation desired outcome was achieved by abstracting a UML Sequence Diagram Template provided by draw.io [17], retrofitting content and context, for the case study of creating a digital twin system. Finally, use of a sequence diagram preserves the process and technology principles outlined by Deloitte, while effectively segregating the manufacturing context that is heavily implied in most Digital Twin research today. It assumes that message sequencing and interoperability of signalling information is a shared function of any Digital Twin and aims to describe the sequence of creating a digital twin as an technological entity that is “self-organizing in the sense that interactions between individuals and the build environment form self-reinforcing patterns of spatial and temporal allocations.” [16]

A digital twin intelligence core architecture is also described in detail. The architecture posits adapting the context of a BDI-Agent driven system into a conceptual cognitive driven intelligence core for the human to machine interface. The BDI system acts as the brain (intelligence), sensory actuators are part of the ABM system. The context and content is adapted from the paper “Integrating BDI Agents with Agent-Based Simulation Platforms” [18] and describes a high on messaging and communications exchange friendly architecture.

Figure [15]



(Abstract) create digital twin system (class) => digital/physical environment - sequence & functions()
[1] Create
[2] Communicate
[3] Aggregate
[4] Analyze
[5] Insight
[6] Act
[7] Aggregate
[n] Repeat DevOps Iteration n+1
sensorOutfitting()
measurements()
signaling()
connect()
edgeProcessing()
comminterfaces()
relationships()
fullStackSecurity()
transformDataObjects()
visualizeComms()
quality()
predict()
- user validation
- gating check
continuousImprovements()
devOps()
createDigitalTwin()
continuousImprovements()
sensorOutfitting()
Message Sequence Protocol - Intelligence Engine (Human) Computer Interface
Signalling() Signalling() Signalling() Signalling() Signalling() Signalling() Signalling() Signalling() Signalling() Signalling() Signalling()
[1] & [2] [1] Create & [2] Communicate
[3] & [4] [3] Aggregate & [4] Analyze
[3] & [4] [3] Aggregate & [4] Analyze
[5] & [6] [5] Insight & [6] Act
[n] [n] Repeat DevOps Iteration n+ 1
Digital Twin Profile Book of Record (BoR)
Public (BoR)
Private (BoR)
params
params
[3] Aggregate
[3] Aggregate

Signalling	**Create Digital Twin Sequence - Overview** [16]		
	Activity {Classes}	**Description**	**Functions/Methods**
	[1] Create	Measurement parameters are derived from sensor outfitting generating a digital twin profile of **sensor actuators** as **configuration parameters (params)**, signalling of measurements is established to occur on demand with a BoR, full security stack {internal and external} where any communications occur; signalling implies that communications of measurements (dynamic profile) occurs at all times	sensorOutfitting() ⇔ measurements() measurements()⇔ signalling() fullStackSecurity()
	[2] Communicate	Establish integration connections, enable interoperability with communication interfaces and document dynamic relationships (signalling) between twins as actuators	connect()⇔ edgeProcessing() commInterfaces()⇔ relationships() fullStackSecurity()
	[3…[7] Aggregate	Manage transformation of data objects within a info/data aggregation process, this type of manipulation will be required to generate analysis and predictions. Aggregate and reconcile with continuous improvements process.	transformDataObjects() predict() continuousImprovements() fullStackSecurity()
	[4] Analyze	Visualize analysis and predictions into consumable communication objects and apply system quality and compliance procedures	VisualizeComms() quality()
	[5] Insight	Perform democratized user validation and gating; validate quality (of predictions) and assess continuous improvements	{User Validation} ⇔ {Gating Check} continuousImprovements()
	[6] Act	Create and operationalize the digital twin object	devOps() createDigitalTwin()
	[n] Repeat DevOps Iteration n+1	Perform updates to sensor outfitting by distributing configuration(s) to the digital twin sensor actuators (and profile) documenting updated measurements; leverage optimized create and communicate processes to address continuous improvements	sensorOutfitting()⇔measurements()

The message sequence protocol aims to provide guidelines for loose coupling of process, classes and functions, as well as how (twin profile) configuration(s) and data should be managed within a BoR. Microsoft describes the digital twin in a form of a journey with three stages that couple the system sequences very well. See figure below for coupling recommendations and rationale. It is recommended that the following steps be functionally paired and highly interoperable from a system's perspective:

Coupling recommendations	**Rationale** [19]
[1] Create, [2] Communicate, [n] Repeat DevOps	**Stage 1:** Remote monitoring of smart connected products with predictive analytics • Connected devices, exchange and signalling of information (IoT) • A unique bond between the end user, digital twin and enterprise/organization • Continuous improvement process that is an optimization of the creation process based on predictive analytics and end user engagement
[3] Aggregate & [4] Analyze	**Stage 2:** A platform for deep insights • System twin as a virtual ontology • Insight factors are object lifecycle driven • Twin provides "deep view into the mechanical, electrical, digital components"
[5] Insight & [6] Act	**Stage 3:** Smarter machines (entities) for a smarter business • Simulates and predicts machine to human interaction • Applies cognitive services (AI, DL, ML) • Predicts and recommends improvements

A general assumption is that signalling between entities (human, object or machine) drives these relationships and the extent that each are relevant throughout the creation process can be tailored or re-aligned during execution for when there is active signalling between twins. Again, it is assumed that any communication, message exchange and or signalling has a full stack of security protocols applied at all times; that being said, security management falls within Communications process wise and the red bars signify some sort of exchange in communications occurring between system features and a bed or book of record (BoR) of data somewhere.

The message sequence protocol also suggests that the first part of the creation process can generally be used as a DevOps inspired intake and planning mechanism for any digital twin configuration(s) or profile changes, where configurations are data-driven and parametric, and the profile configuration data is managed within the BoR, separate from feature functionality.

What's more important is the Digital Twin Profile Book of Record (BoR). With both a private and public BoR, certain sensitive information about city patterns, especial those that can describe "city dynamics in different spatial and temporal resolutions" [16] can be privatized for internal consumption; given internal civic/city dynamics and the right to privacy for a citizen, city specific decisions, don't necessarily need to occur in the open; in fact, for example, predictive models may have a significant amount of proprietary insights and intellectual property as data, still valuable to the city, such models should not be made open for consumption or review

- "understanding how cities respond to change in predictable fashion will also reveal the associate orders and states, thus providing useful predictive insight that could guide smarter management decisions" [16]

System wise, a dedicated BoR for data separate from feature functionality also allows for just in time data requests for specific analysis, operationally more efficient, given data can be staged as required.

Digital Twin Cognitive Driven iCore Architecture: Abstract Model

Focus will be placed on the abstract modelling of how two independent BDI[Belief-Desire-Intention]-ABM[Agent Based Model] systems, as actors in a use case, are integrated into a fluid framework, conceptually summarizing a proposed system context and architecture for a cognitive driven digital twin intelligence core. The modelling technique adapted from is a UML driven system use case, with two actors that represent a twin model, the Brain (BDI Agent) and the Body (ABM Agent).

Digital Twin {BDI-ABM} System Context and Feature Set Concept

In designing an BDI-ABM integrated agent, the conceptual framework proposes a system context and feature sets that distinguishes BDM-ABM functionality as depicted in the figure below [18]; the BDI System is the intelligence (Brain) and the ABM System is the sensory actuators (Body) where the focus is communications and synchronization between the respective agent systems:

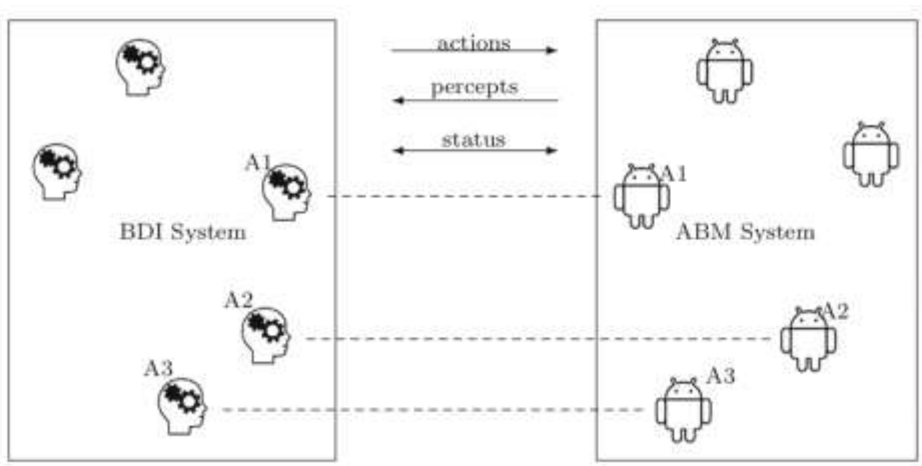


Fig. 1 Conceptual BDI-ABM integration architecture

The algorithm pseudo code is noted in the figure below [18]:

Algorithm 1: Algorithm for the BDI-ABM runtime execution; comments indicate the integration layer (G: Generic, S: System, A: Application) in which the code executes

```
BDI and ABM applications initialised //*
A Links established between BDI-ABM agent counterparts //*
A for each time step do
    ABM sends packaged information to BDI module //*
    G Information is distributed to individual BDI agents //*
    S for each BDI agent do
        execute until idle (possibly querying ABM counterparts) //*
        S notify new actions or action status changes //*
        A
    BDI sends packaged information on agent actions to ABM //*
    G Information is distributed to individual ABM agents //*
    S for each ABM agent do
        execute one time step //*
        S package percepts and action status //*
        A
```

The system context and high-level requirements is summarized in the table below, with loose alignment of the above pseudo code noted for each function. The content is adapted from [18].

Legend:

Body (ABM) Functions	Brain (BDI) Functions	Status / Communications / Integration

Note: Not all points or nuances covered inside of the paper are discussed in the below table, only the high-level points are summarized. Also, relevant Algorithm lines are correlated with each cell, referenced as Lines of Code (LoC).

<table>
<tr><th>The Body (ABM System)</th><th>The Brain (BDI System)</th></tr>
<tr><td>Actions are carried out by the ABM system, the physical representation of the environment, while also being responsible for sending percepts to the BDI system for rationalization

LoC: 1, 2, 4</td><td>Rationality and decision making (definition of actions) are a BDI system component, the cognitive component, performing reasoning cycles

LoC: 1, 2</td></tr>
<tr><td>The Body receives planned / rationalized / reasoned actions from The Brain or BDI system

LoC: 10</td><td>The Brain receives precepts from The Body or ABM system

LoC: 4,</td></tr>
<tr><td>Percepts are typically a bundle of lower level observations in the environment and be distributed to individual BDI agents

LoC: 11, 12</td><td>Similarly, Actions are a bundle of sequenced (lower level) actions for interpretation by The Body's individual ABM agents

LoC: 5,6</td></tr>
<tr><td colspan="2">Operations are synchronous, with a status underlying the information being passed (percepts/action) being a key tie that binds.
LoC: 8, 14</td></tr>
<tr><td>The Brain is time-stepped and operates on a simulation clock
LoC: 7, 13</td><td>The BDI system is even-based, and doesn't model time explicitly
LoC: 7, 13</td></tr>
<tr><td colspan="2">The Brain recognizes that The Body (and environment) is dynamic, subject to the laws of time, and therefore doesn't fully commit to a plan, but relies on status communications from The Body to provide guidance on sequence and timing of actions, in other words, just in time instructions for execution of actions based on status of actions (coming from The Body). These types of nuances in control and communications between The Body and The Brain can be facilitated by
A master / slave relationship; or
An external controller / orchestrator to manage integration
LoC: 3, 7, 13</td></tr>
<tr><td>The Body is the master, driving the integration</td><td>The Brain is the slave (or navigator of sorts), and provides direction when called upon by The Body to perform a reasoning cycle</td></tr>
</table>

Integration Architecture Overview

The integration architecture is noted in the figure below [18] pg1059

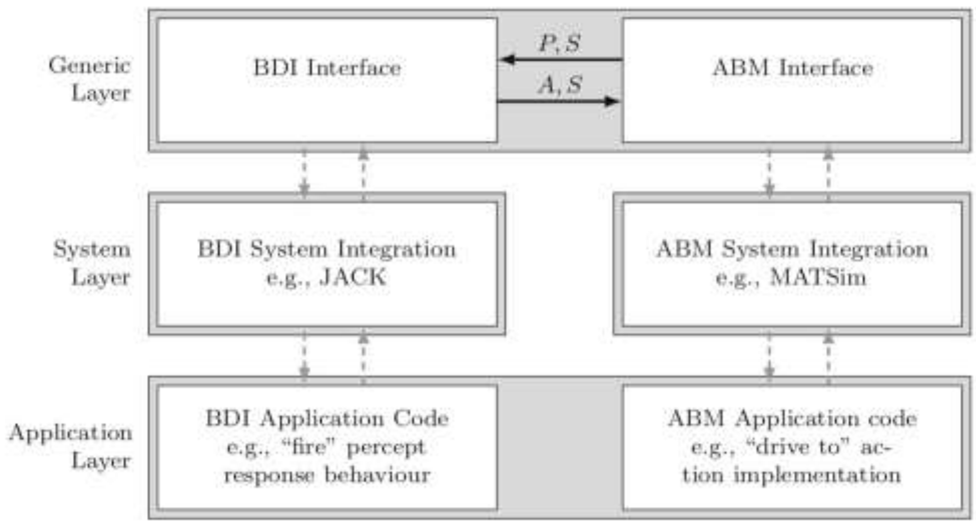


Fig. 4 Three-tiered BDI-ABM integration architecture showing information flow in each synchronised simulation step; ABM system sends percepts list P to the BDI system and receives back actions list A; S is the list of actions' status'

The integration architecture is summarized in the table below. The content is adapted from [18].

<table>
<tr><th>Layer</th><th>The Body (ABM System)</th><th>The Brain (BDI System)</th></tr>
<tr><td rowspan="2">Generic</td><td colspan="2">• Key Interface Layer (ABM ←→BDI)
• Manages control and synchronization
• Manages information flow via [data] containers that consist of i) BDI Actions, ii) Percepts, iii) Queries</td></tr>
<tr><td>• Initializes & Terminates BDI system
• Creates & Destroys BDI counterpart agents
• Percepts: Percepts provided to the BDI (information about the environment/actions to be perceived by The Brain)</td><td>• BDI System pulls precepts from the ABM
• BDI Actions: Durative actions initiated by BDI agents and executed by ABM agent
• Queries: Just in time requests for information from ABM (The Body)</td></tr>
<tr><td>System</td><td>• Update action status
• Collection & distribution of actions/percepts/status internally
• Synchronization functions</td><td>• Model to manage durative actions and reasoning cycle (start/end)
• Collection & distribution of actions/percepts/status internally</td></tr>
<tr><td rowspan="2">Application</td><td colspan="2">THE CODE!
• Clearly delineating “what reasoning is to be performed in which system”</td></tr>
<tr><td>• Code to accept and implement BDI actions
• Code to collect percepts from agents to be sent to the BDI
• Application scenario (i.e. # of agents given configuration)</td><td>• Defining BDI Actions
• BDI deliberation</td></tr>
</table>

Conclusion

This paper provides a bird’s eye top down view of a process and technology ontology for a digital twin. Economic, Research and Development drivers are represented by a new Sharing Economy outlook, technology is increasingly being optimized as a result of sensory tools including IoT, Virtual Reality as an umbrella (including mixed and augmented reality), and immersed experiences; this can be both in a virtual and real setting.

The technical components provides measures and methods that can be leveraged to drive creation of a digital twin, not only proving the potential of a product, but that the concept is not only relevant to manufacturing but that industry 4.0 in general will also serve the civic sector with unforeseen tools and innovations that are cognitive and immersion driven, given a stronger interoperable bond between the underlying technology, platforms and end users. The proposed digital twin model is also designed for flexibility and tailoring in applying process assets and aligning process with system features and functionality. This in effect is an example of how aspects of modelling today need to evolve, clearly design thinking driven, towards an abstract higher level, working towards standardizing the twinning of entities in general as a progressive design and modelling technique. As the new going says => If it isn’t broken, the goal in a sharing economy, is [digital] twin it.

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