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Dharmendra Sharma
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Fusion of Smart, Multimedia and Computer Gaming Technologies

Research, Systems and Perspectives

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Preface

Artificial Intelligence (AI) is a field of study related to developing intelligent computer systems to solve difficult problems which may be well or badly structured and arising from different disciplines and domains. Often a multidisciplinary-based approach is required. Much research and development effort is directed towards investigating computational models for such problems with complex characteristics. The hunger for new, efficient, effective and intelligent technologies continues to grow providing a rich environment to permit researchers and innovators to meet the challenge. New research frontiers in AI aim to fuse (or integrate) smart, multimedia and gaming technologies to deliver innovative solutions that ultimately result in benefits to society. Research and innovation combining these areas provide a rich paradigm for solutions and empowerment connecting computers, systems, organisations, individuals and communities.

We have chosen seven world-class contributions from eminent authors for this monograph. These chapters will provide readers with an opportunity to explore developments in research, systems and perspectives on the fusion of smart, multimedia and gaming technology. The chapters include research results and innovative applications to illustrate the importance of fusion technologies to intelligent solutions. The main areas covered include a variety of new trends: the fusion of 3D virtual technologies, serious applications such as fusion of multimedia and mobile technology in auto guides for visitors in museums and exhibitions, fusion technology in the modern classroom, fuzzy logic classifiers and conceptual modelling for an e-Learning framework, teaching and promoting smart Internet-of-things solutions using the serious-game approach, the fusion of secure VPNs with mobile computing and multimedia, and smart gamification and smart serious games.

With the significant combined experience of the editors in research and publications, we are proud to offer this collection of authors and their wealth of knowledge as presented. The collection will benefit both researchers and innovators. It also generates further research in new directions. We have found the breadth and depth of the research results reported here stimulating, and believe you will too.

Thanks are due to the authors and reviewers for their excellent contribution. We are grateful to the Springer-Verlag and their team for their contribution during the preparation phase of the manuscript.

September 2014

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Contents

Chapter 1
Advances in Smart, Multimedia and Computer Gaming Technologies

Margarita Favorskaya, Dharmendra Sharma, Lakhmi C. Jain and Robert J. Howlett

Abstract The chapter summarizes the contents of this book highlighting recent advances in smart systems, multimedia, and serious gaming technologies through a fusion of these approaches. Such fusion is a nascent area that potentially can hybridize the features and advantages of the relevant areas, and, as a result, provide users with advanced and enhanced functionality and features, which currently does not exist.

Keywords Fusion technologies · Smart systems · Gamification · Serious games · Fuzzy logic evaluation · Learning activities · Scenario development environment

1.1 Introduction

During the last decade, there has been a huge growth in the area of computer-based training systems, which provide a fusion of smart, multimedia, and serious gaming technologies in various scopes including education, industry, business, health, and tourism. Such systems employ recent advances in virtual reality techniques to create

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3D virtual environments with avatars, which increase the usability of these projects significantly. Serious gaming platforms combine methods and concepts of game technology (computer graphics, multimedia, 3D virtual reality, etc.) with sciences (computer science—information and communication technologies, design, psychology, pedagogy, etc.) in "serious fields of applications" such as designing and educational processes, assessment processes for extreme situations, data driven pattern extraction and predictive modeling in health among others. The goal of these investigations is to implement smart, multimedia, and gaming possibilities as challenges in research, investigation of internet of things as an environment for modeling and creation of services, development of human centered services through data analytics and avatar modeling, and creation of prototypes for commercial products.

1.2 Scope of the Book

The main purpose of this book is to present research results on recent advances in smart, multimedia and computer gaming technologies and it includes seven chapters.

Chapter 2 introduces the main terms in serious games. The term "gamification" means the implementation and active use of computer game design concepts, game thinking, game mechanics, game analytics and computer game technology in business models, core activities, processes, procedures, services, products, etc. to improve user skills, experience, engagement, effectiveness, and productivity outside the pure entertainment area [1]. The performed analysis of multiple additional publications relevant to research, description of pilot systems and applications, current use and future trends of smart technology/systems in industry and businesses clearly shows that smart gamification will be an important research topic in the imminent future and in the following 5–10 years it will be adopted by society [2, 3]. These are the main reasons that it is necessary to understand now this emerging technology, classify its main components and underlying technologies, features and attributes, and formulate requirements to produce well-skilled developers of smart gamified applications and serious games. The reader can find multiple Tables with key factors, references, smart entities, etc. in smart school, smart material, smart home technologies, and industrial applications [4, 5].

Chapter 3 discusses the main concepts of advanced Web-Based Rich Multi-Media (WBRMM) systems incorporating the active use of mobile devices, technology and Web, and multiple types of the Rich MultiMedia (RMM) such as static text, dynamic textual communications technologies [6, 7]. The Virtual Private Network (VPN) technology proved to be one of the most reliable technologies to provide data protection, confidentiality, integrity, data origin authentication, replay protection and access control in mobile computing. This chapter presents the outcomes of a multi-aspect research project aimed to design and develop IPsec VPN-based highly effective (in terms of both security and performance) communications in the WBRMM systems, including conceptual, design, architectural, and performance-security-cost modeling of those systems [8, 9]. Various popular encryption standards and protocols are considered.

Chapter 4 studies a methodology for augmented teaching and promoting smart Internet of Things (IoT) solutions. The distinctive feature of the proposed approach is that the simulated situation is notably close to that found in reality. The IoT domain model is based on such assertions as: “Physical objects are integrated to the network over the internet”, “Physical objects are active participants in business processes”, and “In the usage of these objects, the privacy and security issues are highly valued” [10, 11]. The smart-solution concept is notably important in the context of this chapter. The stimuli are obtained from the environment using different sensors and make a response using the knowledge and the actuators that are connected to the system [12]. The other important feature of the presented approach is the model-driven IoT development method [13, 14]. The goal model, decision model, process model, data model, user interface model, and integration model define the solution, and the user can strictly begin to test the application. All the presented solutions are usable on mobile devices.

Chapter 5 provides a conceptual model based on Fuzzy Logic Evaluation Subsystems (FLESs) to implement a “Theory of probability” curriculum. The customized sub-system is used to dynamically evaluate student knowledge [15]. The FLES is designed to gain the students attention, highlights the lesson objective(s), stimulates recall of prior knowledge, and progressively elicits new material to guide increased performance by providing feedback using benign assessment to enhance retention [16, 17]. The proposed system implements three interfacing strategies based on fuzzy logic such as task selection, evaluation, and prompts to help students acquire knowledge. The strategy of tasks selection involves creation of tasks sequence, assignment of complexity level of current task, and definition of numbers of tasks. The teacher makes a decision on relevance of task selection in a current topic, course module, or the whole course. A set of designed fuzzy rules reflect the methodology, which is used by the teacher. The proposed evaluation system is designed as a functioning plug-into the universities “Moodle” server to leverage from the existing course management, learning management and a virtual learning environment.

Chapter 6 presents Innovative Technologies for an Engaging Classroom (iTEC), which provides software tools to design and build scalable learning and teaching scenarios as realistic visions for the future classroom [18, 19]. Eduteka is a toolkit of technologies for advanced learning activity design, components of which provide support for the iTEC pedagogical approach. The Composer tool helps teachers to find, create, and adapt learning activities and share them within their community. The Widget Store can be integrated into the Composer or be used as an independent tool [20]. It allows teachers to search the store themselves and find popular widgets [21]. The Persons and Events Directory as an additional useful tool allows the registered users to find other persons that can contribute to a learning activity or to detect events of interest to a teacher or students in their learning activity. The approach is based on the Scenario Development Environment (SDE) and makes personalized for each user recommendations. The User Management and Access Control (UMAC) framework integrates protocols into the iTEC environment.

Chapter 7 investigates the issues of 3D Virtual World (VW) technology, which improves user experience and enables new application domains [22, 23]. The 3D VW "vAcademia" has been used as a platform for experimental design, implementation, and evaluation of student knowledge [24]. The chapter presents designed tools for collaborative work, for example, an interactive virtual whiteboard as the main tool in graphical content of the "vAcademia". The capturing of real-life activities with motion tracking for implementation in 3D VW is one of interesting decision of this project. Also many other computer vision technologies are involved including Kinect and iPad for controlling virtual whiteboards, gesture recognition, etc. Finally, three scenarios are considered such as annual shareholder meeting, working with customers, and working in distributed teams that opens new possibilities of the designed project.

Chapter 8 describes new approaches in audioguides systems based on fusion of multimedia and mobile technology [25–27]. One type of original software tool is based on Bluetooth connection to a server is and suitable for small painting exhibitions. The authors believe that using visitors' smartphone is a good way to reduce investments and maintenance costs. The other type of applications is dedicated to a large exhibition and uses a database with stored and edited content, when visitors have get access to information through a content generator. The last one was tested in cooperation with Océanopolis [28], a scientific Marine Park. The proposed model is based on domain ontologies that can enhance the informational potential of objects in a museum catalogue. The chapter includes detailed description of software/hardware tools, many informative schemas, and screenshots of designed client-server application.

1.3 Conclusion

This introduction has provided a brief description of seven chapters comprising this book focusing on a narrative on innovative educational, industrial, and business technologies and their hybridization in solving complex, real world research and service-oriented solutions. All the included chapters explore the recent achievements in smart gamification and serious games, advanced Web-based rich multimedia systems, augmented teaching and promoting the smart internet of things solutions, a fuzzy logic evaluation sub-system used to dynamically evaluate of student knowledge, the innovative technologies for an engaging classroom (iTEC Eduteka) for scalable learning and teaching scenarios as realistic visions, 3D virtual worlds for serious applications, and multimedia/mobile technologies in audioguides systems implemented as museums and exhibitions applications. Each chapter of the book includes results of software/hardware design and provides rich URL resources and indications of future developments. This compilation of advancement in the theme areas provides a rich set of resources for future work, and we expect to continue developing this resource through future publications of original contributions through this series.

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Chapter 2
Smart Gamification and Smart Serious Games

Alexander Uskov and Bhuvana Sekar

Abstract The nascent technologies—smart serious games and smart gamification—potentially present an effective fusion of smart technology and smart systems on one side, and applications of computer game mechanics in “serious” areas and gamification of business processes on the other side. They can combine the features and advantages of both areas, and, as a result, provide the end users with non-existing functionality, features and advances. This chapter is aimed to analyze current status of serious games and gamified applications in industry, examine “smartness” maturity levels of smart objects and systems, classify main components and features and present conceptual design model of smart serious games and smart gamified applications, identify technical skills required for a design and development of smart serious games and smart gamification of business, research and development processes and simulations.

Keywords Smart serious games · Smart gamification · Smart objects · Smart systems · “Smartness” maturity levels

2.1 Introduction

A fast proliferation of connected smart devices, smart systems, and emerging smart technologies provides users with enormous opportunities in terms of new approaches to carrying out of main business functions and processes, worker’s higher personal productivity and efficiency, reduced time and better quality of services provided. On the other hand, recent advances in computer gaming technology,

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digital games design, computer game engines stimulated active research in gamification of processes and activities in "serious" areas such as simulation of complex physical objects and phenomena, engineering, project management, healthcare, chemistry, planning, marketing, and other areas.

A combination of smart technology and smart systems with serious games and gamification technology is a nascent area that potentially can combine the features and advantages of both areas, and, as a result, provide users with non-existing functionality, features, and advances. In accordance with the IBM [1]:

- Smarter serious games can help users to solve serious problems because of active use of sophisticated visualization techniques, principles and technologies of computer and video games, smart systems and by active engaging users into problem solving process through curiosity, intrigue, innovation, competition, teamwork, creativity, collaboration, and crowdsourcing.
- Knowledge workers can run sophisticated contextual simulations of complex business processes or multipart systems or phenomena of different physical nature; however, sorting and interpreting experimental data often may fail to keep user's attention; smarter serious games can help users to be focused on actual real-world scenarios and situations, apply different variables to various potential solutions and test those solutions, provide real training of users, change their skills and behaviors.
- Organizations are straining to interpret massive data produced by complex corporate computer information, manufacturing, security/safety monitoring, and other systems, and apply these data to make information-based decisions that minimize possible risks; smarter serious games-based analytics may help workers to process huge amounts of rough data and present essential outcomes in such a simplified way that even non-expert can understand it.

These days, only a few publications with a focus on smart gamification and/or smart serious games exist. As a result, we believe this nascent technology is at the very beginning of the "technology trigger" stage of the Gartner's "Hype Cycle" for emerging technology [2] and "innovators" stage of the Roger's "Diffusion of Innovation" technology adoption typology [3] (Fig. 2.1).

The chapter is organized as follows. Section 2.2 represents state-of-the-art in smart system and gamification markets. Smart systems, smart objects, and smart technology are discussed in Sect. 2.3. Gamification and serious games applications in industry are described in Sect. 2.4. Smart serious games and smart gamification are situated in Sect. 2.5. Section 2.6 concludes perspectives of smart gamification and smart serious games.

2.2 State-of-the-Art

Let us consider state-of-the-art in smart systems' market in 2013–2018 (Sect. 2.2.1), gamification market in 2013–2020 (Sect. 2.2.2), and goal and objectives of current research (Sect. 2.2.3).

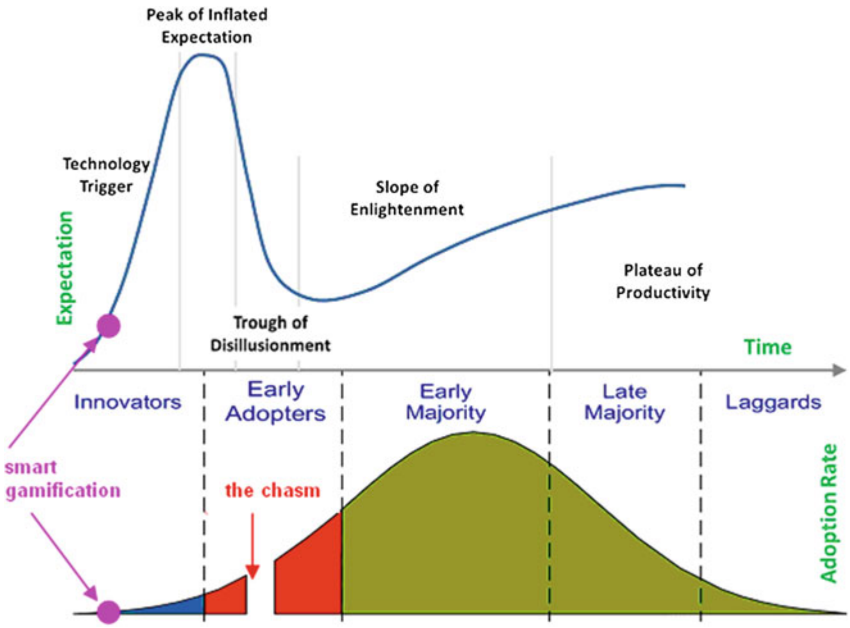

Fig. 2.1 Gartner's "Hype Cycle" for emerging technology [2] and Roger's "Diffusion of Innovation" (technology adoption) typology [3]

2.2.1 Smart Systems' Market

Smart systems' market in 2013–2018. "Smart Systems will drive a multiyear wave of growth based on the convergence of innovations in software architectures, back-room data center operations, wireless and broadband communications, and smaller, powerful, and numerous client devices connected to personal, local and wide-area networks. … The rate of investment in smart systems will be measurably higher than in maturing information technology (IT) and network infrastructure technologies; we are forecasting smart systems growth at 3X the compounded rate of traditional Information and Communication Technologies (ICT); investment in smart systems … will likely increase in scale to as much as 20 % of all of ICT investment within 5 years. A total Smart Systems (SS) market value forecast for 2013 is approximately $275 billion. By 2018, the SS market is expected to grow to $873 billion, representing a 5-year CAGR of 26 %" (Fig. 2.2) [4].

Smart classrooms' market in 2014–2018. "The global smart classroom market will grow at a CAGR of 31.25 % over the period 2013–2018. The two key factors contributing to this market growth are interactive display instruments and 3D education. Multiple global companies are among leaders in this area, including Apple, IBM, Microsoft, and SMART Technologies Inc." [5].

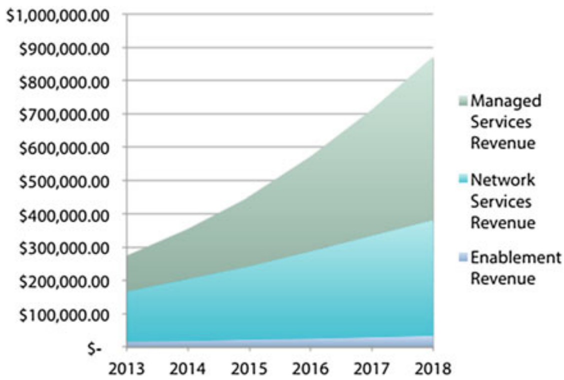

Fig. 2.2 Total smart systems and services market, 2013–2018 [4]

Smart education market in 2013–2017. "The global smart education and learning market is expected to reach $220.0 billion by 2017 at a CAGR of 20.3 % between 2012 and 2017, including (a) services segment with projected $97.9 billion by 2017 with a CAGR of 26.6 %, (b) content segment—$72.9 billion in 2017, at a CAGR of 12.1 %, (c) software segment—$37.2 billion, and (d) hardware—$12.1 billion in 2017. Companies such as Ellucian, Inc. (U.S.), Smart Technologies (U.S.), Blackboard Inc. (U.S.), Kaplan Inc. (U.S.), Promethean World Plc (United Kingdom), Pearson PLC (United Kingdom), and Informa Plc (Switzerland) are among key players on the smart education market" [6].

2.2.2 Gamification Market in 2013–2020

In accordance with [7], "*Gamification* is the use of game design elements in non-game contexts. … Whereas *serious games* describes the use of complete games for non-entertainment purposes, *gamified applications* use elements of games that do not give rise to entire games. … Together with *serious games*, *gamification* uses games for other purposes than their normal expected use for entertainment (asserting that entertainment constitutes the prevalent expected use of games)". As a result, *gamification* means an implementation and active use of computer game design concepts, game thinking, game mechanics, game analytics, computer game technology in business models, core activities, processes, procedures, services, products, etc. to improve user skills, experience, engagement, effectiveness, and productivity outside pure entertainment area.

Currently, gamification is at the Gartner's "peak of inflated expectations" stage (Fig. 2.3) [2].

In accordance with Gartner's predictions [8], "… many small businesses, as well as 70 % of the top 2,000 global organizations, will use "gamified" applications for marketing, employee performance and training, and health care by 2014". According

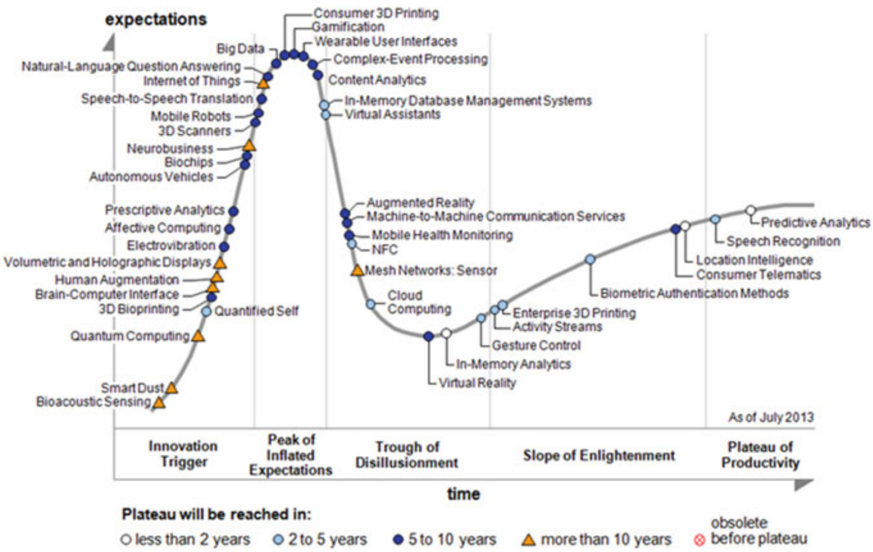

Fig. 2.3 "2013 hype cycle for emerging technologies" by Gartner [2]

to Frost and Sullivan research, global gamification market estimated at around $900 million in 2014 will grow to $8.3 billion in 2020 [9].

2.2.3 Research Goals and Objectives

The performed analysis of these and multiple additional publications relevant to (1) research, design and development projects, (2) description of pilot systems and applications, (3) current use and future trends of smart technology/systems and gamification, gamified applications and serious games in industry and by businesses clearly shows that (a) smart gamification and smart serious games will be an important research topic in several upcoming years, and (b) in the following 5–10 years it is expected to be adopted by society.

The goal of the on-going research project is to understand emerging smart gamification technology and smart serious games, classify their main components and underlying technologies, features and attributes, formulate requirements to produce well-skilled researchers, designers and developers of smart gamified applications and smart serious games.

The objectives of this chapter are to:

- Briefly describe current status of smart technology and smart systems as well as gamification, gamified applications, and serious games in industry.
- Analyze and classify smart entities and their "smart" features and "smartness" levels of smart entities.

- Analyze and classify smart gamification and smart serious games, their mechanics and/or techniques, their features and characteristics.
- Analyze and generalize corporate gamified applications in "serious" (non-entertainment) areas.
- Show a clear difference between smart serious games and smart gamified applications in industry.
- Identify a set of skills for developers of smart serious games and smart gamified applications.
- Predict perspectives of fusion of gamification and smart systems/technology in smart gamification as well as fusion of serious games and smart technology/systems in smart serious games.

2.3 Smart Systems, Smart Objects, Smart Technology…

In this section, the examples of various smart systems will be considered (Sect. 2.3.1). "Systems thinking"-based approach to classification of smart entities is represented in Sect. 2.3.2 as while Sect. 2.3.3 includes smart system characteristics and "smartness" levels.

2.3.1 Smart Systems, Smart Objects, Smart Activities, and Smart Technology

Smart systems and smart technology with various types of "smartness" maturity are already used in industry and businesses; several relevant examples include but are not limited to the following ones.

Smart system example—the Samsung Smart School [10]. The Samsung Smart School solution has three core components (sub-systems): the Interactive Management Solution (IMS), the Learning Management System (LMS), and the Student Information System (SIS). Its multiple unique features and functions are targeted specifically at smart school impact on education and benefits, including Increased Interactivity (II), Personalized Learning (PL), efficient Classroom Management (CM), and better Student Monitoring (SM). The details are available in Table 2.1 [10].

Smart object example—a smart material [11]. Smart material can detect certain signals, adjust sensitivity according to environmental changes, or restore degraded sensitivity. Categories of smart materials include piezoelectric, electrostrictive, magnetostrictive, shape memory allows, optical fibers, catalytic and textile materials. The example of smart textile materials is a smart T-shirt: "… in battle soldiers could wear a T-shirt made of special tactile material that can detect a variety of signals from the human body, such as detection of hits by bullets. It can then signal the nature of the wound or injury, analyze their extent, decide on the urgency to react, and even takes some action to stabilize the injury".

Table 2.1 Key features, impact and benefits of the Samsung Smart School solution [10]

The Samsung Smart School solution					
Core subsystems	Key features	II	PL	CM	SM
Interactive management (management of communication capabilities between teacher and students)	Screen sharing	•		•	•
	Content sharing and remote app execution	•		•	•
	Group activity	•	•	•	
	Remote control and monitoring of student tablets		•	•	•
	Messaging and Q&A	•	•	•	•
	Quizzes and instant polling	•	•	•	•
	Split screen	•	•		
	Enhanced pen stylus	•	•	•	
Student information system (for managing student information)	Monitoring of student attendance	•	•	•	•
	Management of special education plans	•	•	•	•
	Management of student contact information	•	•	•	•
Learning management system (to be used during and after class to help teacher with classroom management and lesson planning)	Upload and share course materials (files)		•	•	•
	Create schedules		•	•	•
	Post to school/subject boards	•	•	•	•
	Access student information (files)				•
	Participate in forums	•	•	•	•
	Create tests and quizzes			•	•
	Send/Receive messages		•	•	•

The legend used: *II* increased interactivity, *PL* personalized learning, *CM* efficient classroom management, *SM* better student monitoring

Smart technology example—the Savant smart home technologies [12]. Smart home technologies provide users with an unmatched level of efficiency, simplicity, control, and automation. Particular smart home technologies include:

- Home or room climate control technology that is aimed at monitoring and control of heating, cooling, air freshness, thermostats, windows shades, draperies.
- Intelligent lighting technology that is focused setting, activation and deactivation of numerous possible lighting schemes at "smart home".
- "Smart home" energy technology is aimed to reduce energy consumption, conserve resources and save money—all without sacrificing comfort or convenience.

- “Smart home” safety and security technology with a “single press of a button” will lock exterior doors and activate doors’ and windows’ security system(s), view surveillance cameras, motion detectors, links to the local police station or a private security company, etc.
- “Smart home” scheduling technology is aimed to schedule watering the lawn, turning lights “Off” or “On”, and others.

Smart activity/process example—the Decimal Software LLC smart shopping list application [13]. Smart shopping activity may be supported by smart phone with multiple applications to help a customer to:

- Support multiple shopping lists.
- Create reminders in a calendar for desired items or a list.
- Assign aisles to items to help guide a customer through the store in a preferred order.
- Add a budget available to the shopping list—in this case each item will show a subtotal to help customer to stay within desired budget.
- Manage item’s expiration date.
- Store anything with a barcode like discount coupons.
- Provide local currency support (currency conversion), etc.

2.3.2 “Systems Thinking”-Based Approach to Classification of Smart Entities

The above-mentioned examples as well as numerous additional examples of smart entities could be classified using the “Systems Thinking” approach, i.e. in terms of smart systems, smart objects, smart activities/processes, and smart technologies/ services (Table 2.2).

Despite the great variety of known and emerging smart entities, their features (or functions) are defined by smart systems’ features [11]. In Table 2.3 the adjusted and significantly extended version of that classification is proposed along with added sections of goals and components.

2.3.3 Smart System Characteristics and “Smartness” Maturity Levels

Based on “Systems Thinking” approach, the description of nine main characteristics of a smart system are given in Table 2.4 including goal, components, links, inputs, outputs, interfaces, constraints/limits, boundary, and environment.

In general case, a smart system may contain a number of subsystems, and, in its own turn, a subsystem may contain a huge number of smart objects. For example,

Table 2.2 Classification of smart entities (with examples)

Classes of smart entities	Examples of class instances
Smart systems	Smart phone
	Smart classroom
	Smart school (university)
	Smart city
	Smart society
Smart objects	Smart sensor (transducer)
	Smart fabric material
	Smart medical device
	Smart meter
Smart activity/Processes	Smart learning
	Smart gamification
	Smart manufacturing
	Smart shopping
	Smart computing
Smart technology/Services	Smart sensor technology
	Smart RFID technology
	Smart metering (mesh technology or point-to-point technology)
	Smart grid technology
	Internet of Things

in general case, a smart city (as a smart system) may contain several sub-systems—smart energy management, smart transportation and logistics, smart healthcare, smart governance, smart education and smart training, smart security, smart infrastructure, etc., and possibly a huge number of smart objects (sensors, meters, actuators) in each sub-system [9, 14]:

- Smart energy management and distribution and utility network subsystem of a smart city may contain multiple smart objects such as meters of water, electricity and natural gas, parking lot meters, traffic control cameras, security surveillance cameras, etc.
- Smart transportation and logistics network sub-system of a smart city may contain various smart objects such as parking lot management, monitoring of traffic intensity on main city interactions and highways within city, control and monitoring of location of school buses, public transportation buses and trains, emission control, car-to-car communication, control and monitor of traffic lights on major city avenues, etc.
- Smart human/community/society network sub-system of a smart city may contain a great variety of smart objects, for example, various safety-focused sensors: surveillance cameras, fire detection, CO_2 detection, detection of suspicious individuals and substances, radiation detectors, etc.

Table 2.3 Smart entity's features [11] and added goals and components

Features/Functions	Goals	Components
Acquisition (sensing) of real-world raw data or signals, and, possibly, a local pre-processing of raw data	To (1) collect the required raw data needed for an appropriate sensing, and, thus, monitor a situation, condition, object, system, environment, etc., (2) convert sensor data into correct secure format for further processing, (3) in some cases: process data in real-time in a local area network	High-sensitive sensors, transducers, machine-to-machine communication, scene analyzers, local area network, etc.
Transmission of raw data and/or pre-processed sensory information	To transmit the sensor raw or pre-processed data to the local and/or central control unit using safe, secure and flexible communication technologies and/or data exchange protocols	Transmitters, wide area network, Internet, etc.
Big data processing and comprehensive analysis of obtained information (smart analytics) at control units in accordance with real-world business/safety/security models	To manage and control the entire system by (1) receiving required raw data or pre-processed sensory information, (2) smart analytics, including big data processing and complex data analysis—both are beyond human intelligence), (3) producing conclusions, (4) predicting the future based on current data, (5) making decisions, (6) determining the actions required to implement decisions made, and (7) giving instructions to actuators, components, or subsystems of a smart system	Central Processing Unit (CPU), invariant analysis systems, visualization system, big data storage units, data mining systems, predictive analytics systems, pattern analysis systems, etc.
Transmission of instructions	To transmit (a) decisions made and (b) associated instructions produced to actuators or designated smart system's components using secure communication technology and/or data transmission protocols; in some cases, natural language synthesis is needed	Transmitters, wide area network, Internet
Activation (adapting, triggering) of physical and/or virtual actuators	To initiate or take appropriate actions or perform activities to provide system's reaction on received raw data	Actuators, adapters

Table 2.4 Classification of main characteristics of a smart system

Characteristic	Details or comments
Goal (purpose)	To integrate sensors, infrastructure components, processes, technology, users, and analyze/process big data in order to produce quality knowledge, enable collective real-time awareness, complex multi-aspect services, and help end users to make highly efficient on-time crucial decisions
Components (smart objects, smart processes or activities, smart technologies or services) or subsystems (or sets components)	Various components from miniaturized (micro) parts to large sub-systems of a system, for example: (a) a ubiquitous broadband infrastructure, Web-based software systems and applications, hardware/equipment, network technologies, (b) miniaturized connected sensors with broad range of sensing capabilities such as security/safety sensors and surveillance cameras or sensors to monitor human body main parameters (blood pressure, temperature, etc.), (c) managed services, for example, to monitor environment safety, network security, server load, etc.
Links between components	Secure radio/electrical (wired or wireless), physical (mechanical, pneumatic, hydraulic), thermal, Internet-based, infrared, etc. connections
Inputs	Very large amounts of rough data and meaningful information from the environment, for example, from sensors, devices, machines, information systems, people, maps, etc.
Outputs	Quality knowledge-based recommendations and, if necessary, immediate actions using various types of software systems, information technology, Web services, actuators (hydraulic, pneumatic, electric, electronic, thermal, mechanical), etc.
Interfaces	IP Internet protocols, RFID protocols, various types of machine-to-machine or sensor-to-processing unit data exchange and control protocols, etc.
Limits (constraints)	Examples: (a) weight, type, and size of sensors, (b) time to process rough data, (c) form of processed data representation (should be easy-to-understand by end users), etc.
Boundary	It significantly depends on system's purpose; for example, a boundary of a human body, a boundary of corporate office, school classroom or lecture hall, a boundary of a city, etc.
Environment	It significantly depends on systems' scope

- Smart information network subsystem of a smart city may contain numerous smart objects such as real-time big data processing and analysis systems, forecasting of emergency/disaster events and immediate broadcasting/warning in case of high probability of those events, remote maintenance system, etc.

2.3.4 "Smartness" Maturity Levels of a Smart System

In order to differentiate smart systems based on their "smartness" maturity level, the classification of intelligence levels and abilities of smart technologies from [15] is used (Table 2.5); it also contains proposed corresponding examples from computer science and computer engineering.

Table 2.5 Classification of "smartness" maturity levels of a smart system [15] and proposed corresponding examples from computer science and computer engineering

"Smartness" maturity levels	Details	Examples from computer science/ engineering
Adapt	Ability to modify physical or behavioral characteristics to fit the environment or better survive in it	Adaptive networks, adaptive hyper media, adaptive mesh refinement
Sense	Ability to identify, recognize, understand and/or become aware of phenomenon, event, object, impact	Sensors, wireless sensor networks, smart materials, face-in-a-crowd recognition
Infer	Ability to make logical conclusion(s) on the basis of raw data, processed data and/or information, observations, evidence, assumptions, rules, and reasoning	Reasoning systems, expert systems, inference engines, fuzzy logic, big data analysis systems, data mining systems
Learn	Ability to acquire new or modify existing knowledge, experience, behavior to improve performance, effectiveness, skills, etc.	Intelligent agents, genetic programming, neural nets, smart e-learning systems
Anticipate	Ability of thinking or reasoning to predict what is going to happen or what to do next	Robots, smart (driverless) cars
Self-organize	Ability of a system to change its internal structure (components), self-regenerate and self-sustain in purposeful (non-random) manner under appropriate conditions but without an external agent/entity	Traffic networks, Internet connection patterns, some objects at the cellular or nano-technology level

2.3.5 Smart Systems: A Long-Term Perspective

Based on performed analysis and developed classifications of smart systems and entities (Tables 2.2, 2.3, 2.4 and 2.5), we predict that in long-term perspective smart systems will:

- Be used almost everywhere in the physical and cyber worlds.
- Serve as a contact point or a bridge between physical and cyber worlds.
- Stimulate a fusion of physical and cyber worlds; for example, by strong support of a shift from self-sourcing and in-sourcing to cloud sourcing (where specialized cloud products and services and their deployment and maintenance is outsourced to and provided by one or more cloud service providers) and crowdsourcing (where the collective "smartness" of the public and professional community will help to complete business-related tasks that a company would normally either perform itself or outsource to a third-party provider).
- Stimulate an integration of heterogeneous systems to help to control huge chaotic systems, for example, the invariant analysis can detect abnormal situation by extracting internal system dependency from the data without any domain knowledge or super resolution technology can help to enhance the resolution of an image—a face in a crowd from a low resolution surveillance camera.
- Predict possible future problems by sensing current changes (i.e. micro or macro changes, short-term and long-term changes), predict future scenarios and analyze their probabilities, and take preventive actions to eliminate or significantly minimize risks.
- In general, prevent human beings, communities and society from disastrous events.

2.4 Serious Games and Gamification in Industry

The main terms of serious games are described in Sect. 2.4.1. Gamification is discussed in Sect. 2.4.2.

2.4.1 Serious Games

In accordance with IBM, Serious Games (SG) have capabilities to "… (1) solve complex problems collaboratively, (2) make business processes more efficient, (3) achieve predictive modeling and real-time visualization, (4) increase ROI from processes, time, and resources, and (5) provide 108 % more retention of knowledge, compared to traditional methods" [1]. This motivates companies to design, develop, and implement full-scale SG in their business functions and processes. "Business process improvement has been responsible for reducing cost cycle time by as much as 90 % while improving quality by more than 60 % " [16].

The SG definition. We define the SG as follows: *Serious game is a software system that combines "serious" dimension* (*a non-entertainment goal and context*) *and "gaming" dimension* (*game design concepts and models, game structure, game mechanics/techniques, and game-like graphic user interface*).

The SG classification. A well-though classification of the SG is necessary for a deep understanding of the SG purpose, scope, domain, type, gameplay, audience, etc., and, as a result, for a better to-be-proposed fusion of the SG with smart systems and technologies. A variety of possible SG classifications are available, for example, in [17–20]. One of the most detailed one—the G/P/S/ classification [17] is presented in Fig. 2.4.

In accordance with the G/P/S model:

- The SG purpose may be of various types, such as message broadcasting (educative—edugames, informative—newsgames, persuasive—advergames, political games, subjective—military games, and arts games), training (mental or physical), and data exchange.
- The SG scope may consist of game's market/domain (such as state and government, military and defense, healthcare, education, corporate, religious, culture and art, ecology, politics, humanitarian, advertising, scientific research, and entertainment) and public/audience (for example, general public, professionals, and students).

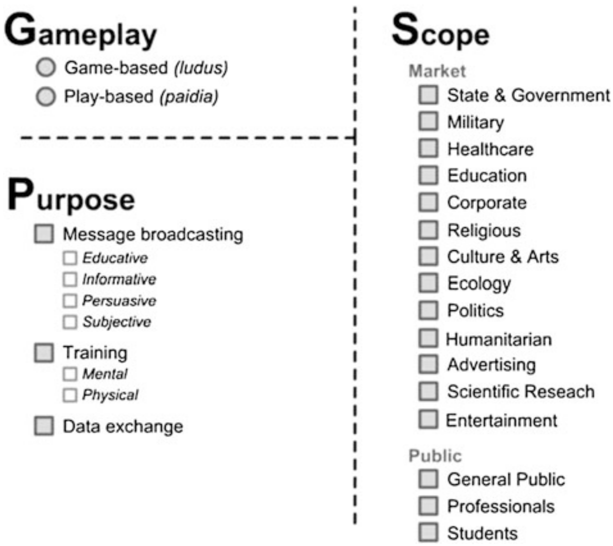

Fig. 2.4 A "printable page" format of the G/P/S model [17]

- The SG gameplay may be of the following types: game-based (with a clear game goal) and play-based (without clear game goal).

Creative power of the SG. Researchers at the University of Washington (U.S.A.) reveal the creative power of crowds playing the developed *Foldit* game. They compared games strategies with the best-known scientist-developed methods to cure AIDS. The game drew 46,000 participants whose gameplay took just 10 days to solve a problem scientists had been working on for 15 years. It generated a crowd-sourced discovery of the mystery of how a key protein may help cure AIDS. Researchers called some *Foldit* game strategies "shocking" in how well they mimicked some of the methods already used by protein scientists [21].

2.4.2 Gamification

Definition of gamification. We define gamification as follows: *Gamification is a process of incorporating "gaming" dimension—game designs, structure, mechanics and game-like graphic user interface into an existing non-entertainment entity "dimension"* (*such as software system, an enterprise mobile application, corporate or learning community, a community of customers, a website,* etc.) *in order to motivate professional development and growth, personal productivity and efficiency, quality of learning or training, active participation and engagement, interaction, and/or long-term loyalty.*

Gamification mechanics/techniques. Game mechanics that are incorporated into a gamified software system or application may have a significant impact on type of player or user, who may or may not efficiently use those techniques and get maximum benefits from it. A compilation of relevant examples that are based on ideas in [22–24] is available in Table 2.6.

Serious games and gamified applications in industry. In accordance with [25], 53 % of surveyed 1,021 technology stakeholders and critics agreed that "… by 2020, there will be significant advances in the adoption and use of gamification". These days many global companies, including Microsoft, IBM, Oracle, Adobe, Cisco, Siemens, SAP, Google, Accenture, American Express, Caterpillar, Ford, etc. already started an implementation of gamification techniques and gamified applications to support their main business functions, processes, and/or activities.

More than 60 examples of successful use of gamified applications in "serious" areas, or *Serious Gamified Applications* (*SGA*), and the SG by various corporations and companies have been reviewed and analyzed by authors; a summary of about 30 relevant analyzed examples is presented in Table 2.7.

Benefits of the SG and the SGA use in industry. The outcomes of performed analysis of successful SG and SGA applications in industry (Table 2.7) clearly show that active use of the SG and the SGA for improvement of business processes amplifies worker's positive psychology, and strengthens and extends the PERMA concepts [26] including:

Table 2.6 A summary of game mechanics, types of players, and their possible benefits [22–24]

Type and name of game mechanics	Details of game mechanics	Types of players	Possible benefits
1. Progression gamification mechanics			
Badges, trophies	An indicator of accomplishment or mastery of a skill; it is especially meaningful within a community or group that understands its value	Achievers, explorers	Engagement, loyalty, influence, time spent, fun, User-Generated Content (UGC)
Points	Used to keep score and establish player's status. Players earn points through activities, sharing, contributing, or by creating something useful to community	Achievers, explorers	Engagement, loyalty, influence, time spent, virality, fun, UGC
Level or status within a professional community	Levels indicate long-term or sustained achievement; they are used to identify status within a community and to unlock new missions, badges, activities, and rewards	Achievers, explorers	Engagement, loyalty, time spent, influence, virality, fun
Leadership boards	Tools to monitor and display desired actions	Achievers, explorers	Engagement, loyalty, influence, time spent, UGC, virality, fun
2. Feedback gamification mechanics			
Quests/ Challenges	"Challenges" usually imply a time limit or competition whereas "quests" are meant to be a journey of obstacles the user must overcome	Achievers, explorers	Engagement, loyalty, revenue, influence, time spent, virality, fun, UGC
Immediate feedback or response to actions	Encourage users to continue or adjust their activities with onscreen notifications, text messages or emails. Congratulate a user for reaching a goal, encourage the next step to a milestone or promote a new reward	Achievers, explorers	Engagement, loyalty, revenue, influence, time spent, virality, fun, UGC
Transparency	Show users exactly where they stand on the metrics that matter to you and to your audience. Individual and team profiles show progress in real-time and historically. Leaderboards show who's just ahead and who's behind as well as overall ranking on any number of metrics	Achievers, explorers	Engagement, loyalty, revenue, influence, time spent, virality, fun, UGC

(continued)

Table 2.6 (continued)

Type and name of game mechanics	Details of game mechanics	Types of players	Possible benefits
Cascading information theory	Information should be released in the minimum possible snippets to gain the appropriate level of understanding	Achievers, explorers	Engagement, influence, time spent, virality, fun, UGC
Appointment dynamics	At a predetermined times a user must return for a positive effect	Achievers, explorers	Engagement, influence, time spent, virality, fun, UGC
Countdown	Users are only given a certain amount of time to do or to complete something	Achievers, explorers	Engagement, influence, time spent, virality, fun, UGC
Combos	Reward skill through doing a combination of things	Achievers, explorers	Engagement, influence, time spent, virality, fun, UGC
3. Behavioral gamification mechanics			
Goals (short- and/or long-term)	Missions or challenges give players a purpose for interaction, and educate players about what is valued and possible within the experience	Achievers, explorers, socializers	Engagement, loyalty, influence, time spent
Epic meaning	Users will be highly motivated, if they believe they are working to achieve something great, something inspiring, something bigger than themselves.	Achievers, explorers, socializers	Engagement, loyalty, influence, time spent, fun, UGC
Discovery or exploration	Players love to discover and to be surprised	Explorers, achievers	Engagement, loyalty, influence, time spent, fun
Community	Community gives meaning to goals, badges, competitions, and other mechanics. Sharing participant achievements creates energy in the community by making people aware of what others are doing. They learn about goals, badges, and rewards that they may want to pursue	Socializers, achievers	Engagement, loyalty, revenue, virality, UGC
Community collaboration	Connect users as a team to accomplish larger tasks, to drive competition, and to encourage knowledge sharing. Show team members how they are contributing to the group's success. No one wants to let down their team members	Achievers, explorers, socializers	Engagement, influence, time spent, virality

(continued)

Table 2.6 (continued)

Type and name of game mechanics	Details of game mechanics	Types of players	Possible benefits
Ownership	Creates loyalty by owning things	Achievers, explorers, socializers	Engagement, loyalty, revenue, influence, fun
Virality	Users are more successful in the game, if they invite colleagues	Achievers, explorers, socializers	Engagement, influence, fun
On-boarding	Players use learning-by-doing paradigm. Simple missions help new users become engaged immediately as they master basic tasks, rather than being stumped by an unfamiliar interface or a detailed manual	Achievers, explorers, socializers	Engagement, loyalty, influence, time spent
Competition	Raise the stakes for accomplishing a goal by showing users how they compare to others, as individuals or in teams. Encourage competition with time-based, team and individualized leaderboards	Achievers, socializers	Engagement, loyalty, revenue, influence, time spent, virality, fun, UGC

- Positive emotions (experiencing joy, pleasure, fun, safety, etc.).
- Engagement (being constantly involved in activities).
- Relationships (enjoyable/supportive interactions).
- Meaning (creating a purposeful narrative).
- Accomplishment (achieving goals, following core values, etc.).

Additionally, the SG and the SGA placed on corporate web site promote [27, 28]:

- Better retention and efficient memorization factors.
- High customization of information.
- Better interactivity and maximum implication.
- Attractive and non-intrusive advertising.
- Better "word of mouth" virality.
- Better dissemination and promotion of web-published information.

Table 2.7 Serious games and serious gamified applications in industry [24]

Company	Main business activity to support	The SG or the SGA used
IBM	Communication (corporate social communication and collaboration)	*IBM Connections*
Oracle	Communication (support of communication to about new software features)	*Prune The Product Tree*
SAP	Communication (corporate social networking)	*Two-Go*
Scrum Alliance	Communication and collaboration (support of software development teams' communication/ collaboration)	*Knowsy*
Qualcomm	Planning (better understand how customers use its products, identify key marketing messages for the launch of its asset-tracking product line, and discover new product opportunities)	*ProductBox*
VersionOne	Planning, communication and collaboration (support of agile software development teams)	*Speedboat, Buy a Feature*
Computer Science Corp	Planning (accelerate time to market)	*Development/Test-as-a-service*
HP	Planning and management (increase of sales)	*Project Everest*
IBM	Planning and management (reduction of cost of internal business)	Document translation
HP	Planning and management (user engagement)	HP Operations Manager
PWC	HR management (employee recruitment)	*Multipoly*
Google	HR management (employee recruitment)	Google code jam
Accenture	HR management (employee flexibility)	*Liquid Workforce*
American Express	HR management (business travel support)	Global Business Travel
IBM	Management (business process management to drive innovation)	*IBM Innov8*
Microsoft	Quality management (improvement of productivity and software quality assurance)	*Language Quality Game, Ribbon Hero*
Cisco	Quality management (improvement of global sales experience)	*The Hunt*
Microsoft	Quality management (gamification of threat assessment process)	*Elevation of Privilege*
Microsoft	Software development (software development/ coding skills improvement)	*Pex4Fun*
	Software development skills improvement)	
Cisco	Testing (testing of network planning skills)	*myPlanNet*
Cisco	Training and team working (building a team and team working)	*The Threshold*
Oracle	Training (employee on-boarding)	New Hire
Siemens	Training and development	*Plantville*
NTTData	Training (leadership training)	*Ignite Samurai Leadership*

(continued)

Table 2.7 (continued)

Company	Main business activity to support	The SG or the SGA used
SAP	Training (sales training)	SAP Road Warrior
SAP	Marketing and branding	*Paul the Octopus*
HP	Improvement of conference papers' selection	HP global technical conference

2.5 Smart Serious Games and Smart Gamification

The outcomes of performed analysis of existing smart entities (Table 2.2), classification of general features of a smart entity (Table 2.3), classification of "smartness" maturity levels of smart entities (Table 2.5), existing serious games and gamification mechanics and benefits for users (Table 2.6), and existing successful the SG and the SGA in industry (Table 2.7) enabled us to predict a further development in those areas:

- *Smart Serious Games* as an efficient fusion of smart systems and/or smart technologies and serious games (Sect. 2.5.1).
- *Smart Gamification* as an efficient fusion of smart systems and/or smart technologies and gamification components—computer game design concepts and methods, game mechanics, game analytics, and game-like graphic user interfaces (Sect. 2.5.2).

Also the SSG and the SGM conceptual design model is presented in Sect. 2.5.3. Skills required for the SGM and the SSG are mentioned in Sect. 2.5.4.

2.5.1 Smart Serious Games

Smart Serious Games (SSG) will incorporate some or all "smartness" abilities of smart systems (as in Table 2.5). This prediction is particularly based on the fact that some advanced analytical adventure games like *Journey*, *L.A.Noire*, *Portal* 2, *Gabriel Knight* already require;

- Raw data collection about current situation, visible obstacles, visible and intuitive opportunities, etc.—it is expected that eventually it will be transformed into "sensing" ability.
- Analysis of raw data and decision making, which will be transformed into "inferring" ability (or smart analytics).
- Adaptation to a level of user skills and knowledge, which eventually will be transformed into "adapting" ability (as in Table 2.5).

A proposed classification of the SSG is presented in Table 2.8 with relevant examples. It is based on ideas of the G/P/S/ classification in Fig. 2.4; however,

Table 2.8 Proposed classification of the SSG

The SSG feature	The SSG characteristic	The SSG details (types, classes)	Relevant examples [18, 19, 24]
Purpose	Decision-making	Mechanisms for making better decisions faster	*ProductBox*
	Simulation	Face-to-face or electronic simulations of situations that might play out in reality	*Packet Tracer, Millennium Challenge 2002*
		Subjective (military games, art games)	*America's Army*
	Sharing of knowledge	Educative (edugames)	*The Beer Game, Autopsie d'un meurtre*
		Informative games (newsgames)	*September 12th*
	Persuasion	Persuasive games	*Dying in Darfur*
	Data collection/exchange/ exploration	Games based on data collection and data exchange	*Portal 2*
		Focus on research, discovery, innovation	*Foldit, Buy a Feature*
		Adventure games	*Journey, L.A. Noire*
	Motivation	Badges, scores and rewards, incorporated into work	*Ribbon Hero*
	Training	Focus on analytical skills	*Lure of the Labyrinth*
		Focus on technical skills	*Prog&Play*
		Focus on management skills	*Innov8, Multipoly*
		Focus on communication skills	*Prune The Product Tree*
		Focus on team working skills and collaboration	*Novicraft, PowerUP, The Threshold*
Scope	Domain	Corporate	*Electro City*
		Education	*Enterprise Battle*
		State and government	*Cyber Budget*
		Healthcare	*Fatworld*
		Marketing	*Flip Mobile*
		Military	*America's Army*

(continued)

Table 2.8 (continued)

The SSG feature	The SSG characteristic	The SSG details (types, classes)	Relevant examples [18, 19, 24]
		Culture and arts	*Grotte de Gargas*
		Ecology and environment	*Climate Change*
		Politics	*Debate Night*
		Humanitarian	*Deliver the Net*
		Advertising	*Blam Blam Fever*
		Scientific research	*Foldit*
	Audience	General public	*Creepy Crossword*
		Professionals	*Maritime Warfare*
		Students (elementary/middle school)	*GeoDefi*
		Students (high school/college)	*Virtual U*
Gameplay	Type	Game-based (with clear game goal)	
		Play-based (without clear game goal)	
	Goal	Choices: (1) Avoid, (2) Match, (3) Destroy	
	Means	Choices: (1) Create, (2) Manage, (3) Analyze, (4) Solve, (5) Move, (6) Select, (7) Shoot, (8) Write, (9) Random	
Smartness (smart features from Table 2.3)	Acquisition (sensing) of real-world data or signals	Adding real-world input data to the SG (for example, acquisition in real-time of real patient's physiological parameters (temperature, blood pressure, pulse, cholesterol level, etc.) as input data for personalization and adaptation issues of the predictive treatment scenarios in serious games-based therapies)	[29]
	Real-time processing of real-world data, inferring, smart predictive analytics	Adding real-world business models and analytics to the SG (for example, processing of real-world big and dynamic data into integrated simulation-based the SG that uses optimization)	[30]

(continued)

Table 2.8 (continued)

The SSG feature	The SSG characteristic	The SSG details (types, classes)	Relevant examples [18, 19, 24]
		techniques to minimize risks due to decisions made in Supply Change Management area	
	Adapting, or activation of physical or virtual actuators	Adding adaptation and/or actuation functions to the SG (for example, resetting of outdoor holiday light decorations by sending actual machine-to-machine data or signals according to smart design system's recommendations)	

it significantly extends by adding multiple additional characteristics (in the "purpose" section, specifically, decision making, simulation, sharing of knowledge, persuasion, data collection/enhance/exploration, motivation) and new unique features (the SSG smart features, from Table 2.3). Particularly, the SSG should provide acquisition (sensing) of real-world data or signals, real-time processing of real-world data, inferring, and smart predictive analytics, and adapting, or activation of physical or virtual actuators. In other words, the SSG will be very instrumental in an effective fusion of real-world (real objects), cyber-world (serious games and/or gamified applications), and smart entities—smart software systems, smart objects, smart technology, smart activities, etc. (as in Tables 2.2 and 2.3).

2.5.2 Smart Gamification

Smart Gamification (SGM) is aimed at a fusion of smart systems, smart features, smart technology, smart sensors, etc., and gamification components—game mechanics, computer game design concepts and methods, game analytics, and game-like graphic user interfaces. The SGM can be implemented using the following approaches:

- Gamification Components (GC) based approach: in this case, a set of software applications with various GCs (such as game mechanics, game design concepts, game-like Graphic User Interface (GUI), etc.) is implemented either directly into current corporate Business Functions and/or Procedures (BFP) or into existing Enterprise software Applications (EAs) that support BFPs.
- Gamification Platform (GP) based approach: in this case, an external GP is used to develop a specialized full scale serious game for a company to support its BFPs—either all business functions and procedures or a sub-set of them.

In both approaches, a required component of either the SGM or the SSG is a set of to-be-implemented smart features (from Table 2.5) including:

- Acquisition (sensing) of real-world raw data or signals, and, possibly, a local pre-processing of raw data.
- Transmission of raw data and/or pre-processed sensory information.
- Data processing and comprehensive analysis of obtained information (smart analytics) in accordance with real-world business functions.
- Transmission of instructions.
- Activation of physical (devices) and/or virtual actuators (software systems and tools).

2.5.3 The SSG and the SGM Conceptual Design Model

Design of the SSG or the SGM depends on multiple factors including existence or absence of corporate software application(s) to be gamified, external gamification platform to be used, existence or absence of appropriate SG, selected set of gamification components, and selected set of smart features to be implemented.

The proposed SSG and SGM conceptual design model is presented in Table 2.9. It clearly shows a process of construction of various types of the SG, the GA, the SGM, and the SSG. The following legend is used in Table 2.9:

- BFP—a set of company's Business Functions and/or Processes (BFP).
- EA—a set of Existing software Applications (EA) to support company's BFP.
- GA—a Gamified Application (GA) to support company's BFP.

Table 2.9 Proposed SSG and SGM conceptual design model

BFP	EA	SG	GP	GC	SF	Outcome	Case (details)
BFP	–	–	–	–	–	–	There are no apps to support BFP; neither gamification nor smart features are implemented
BFP	EA	–	–	–	–	EA	Neither gamification components nor smart features or serious games are implemented
BFP	–	SG	–	–	–	SG	Serious game
BFP	EA	–	GP	–	–	GA-GP	GP-based gamified application (GA-GP)
BFP	EA	–	–	GC	–	GA-GC	GC-based gamified application (GA-GC)
BFP	EA	–	GP	–	SF	SGM-GP	Smart gamification based on GP approach (SGM-GP)
BFP	EA	–	–	GC	SF	SGM-GC	Smart gamification based on GC approach (SGM-GC)
BFP	–	SG	–	–	SF	SSG	Smart Serious Game (SSG)

- SG—external existing fully completed Serious Game (SG) that could be used by a company to support its BFPs—either all or part of them.
- GP—external Gamification Platform (GP) that can be used to develop a specialized SG for a company to support its BFPs—either all or part of them.
- GC—a set of corporate software applications with implemented Gamification Components (GC) such as game mechanics, game design concepts, game-like GUI, etc.; GC are implemented either directly into current BFPs or into existing EAs that support the BFPs.
- SSG—a completed smart serious game for a smarter support of company's BFPs.
- SGM—a set of Smart Gamification (GM) components to better (smarter) support company's BFPs.
- SF—a set of smart features (as explained in Table 2.5).

2.5.4 Skills Required for the SGM and the SSG

Design and development of the SGM and the SSG require solid analytical, technical, and management skills in Computer Science (CS). "A modern, high-end computer game today costs on the order of $50 million dollars" [31].

Substantial collaborative efforts of various specialists in the CS—project managers, software engineers, advanced programmers, graphic user interface designers, human-computer interaction experts, specialists in computer graphics, databases, artificial intelligence, intelligent systems, networking and security—are necessary to produce the SGM and the SSG for real-world complex business functions, procedures, tasks and simulations. As a result, Table 2.10 presents the proposed list of team members for the SGM and the SSG design and development project, their important skills, and an approximate list of courses to be taken to develop skills, required by the SGM and the SSG design and development projects. Details related to proposed skills are available in [32] including, for example, several advanced programming assignments aimed at advanced game programming skills such as operations with 3D vectors, Virtual Machines (VMs) concept, and bit flags; those assignments are going well beyond regular topics and assignments in traditional programming courses.

2.6 Perspectives of Smart Gamification and Smart Serious Games

The research, development, commercialization and acceptance of the SGM and the SSG in society, industry, and businesses will lead to a fusion of physical and virtual

Table 2.10 Proposed lists of the SGM and the SSG team members, their skills and courses to be taken to develop required skills [32]

Type of a member of the SGM or the SSG development team	Examples of required skills	Relevant CS courses to be taken to develop required skills
The SGM or the SGG development project manager	Strong management skills	The SG development project management
	Strong analytical skills	The SG design and development
	Strong system and software engineering skills	The SG engine development
		Storytelling
	Great experience in the SG design and development	Software project management
		Software engineering
		Agile software engineering
		Systems analysis and design
Lead the SGM/SSG software developer or engineer	Strong system and software engineering skills	The SG design and development
		The SG engine development
	Strong software development skills	Advanced game programming
		Advanced game engine modification
		Storytelling
		Software engineering
		Agile software engineering
		Web and mobile software systems
The SGM/SSG software developer and/or programmer	Strong software development skills	Advanced programming in C++, C#, Java, PHP, Assembler
	Strong programming skills	The SG design and development
		The SG engine development
		Advanced data structures and algorithms
		Applications of data structures and algorithms
		Advanced game programming
The SGM/SSG network developer and/or programmer	Strong knowledge of networking, operating systems	Computer architecture
		Operating systems
		Net-centric computing
	Strong knowledge and skills in Web services and Web programming	Integrative programming and technology
		Open Computing Language (OpenCL)
		Web technologies and services

(continued)

worlds, and, as a result, to a design, development and formation of a smarter

Table 2.10 (continued)

Type of a member of the SGM or the SSG development team	Examples of required skills	Relevant CS courses to be taken to develop required skills
	Strong network security knowledge	Information technology infrastructure
		Computer networks and system security
		Mobile and wireless networks
		Advanced mobile programming
Computer graphics developer and/or programmer	Strong computer graphics skills	Linear algebra
		Computer graphics
	Strong GUI development skills	Advanced computer graphics
		OpenGL
		Advanced GUI and Human-Computer Interfaces (HCI)
		Image and pattern recognition
Physics and characters programmer	Strong programming skills	Physics
	Excellent knowledge of physics	Advanced physics
		Developmental psychology
System security developer and/or programmer	Strong skills in secure coding	Integrative programming and technology
	Strong integrative programming skills	Computer networks and system security
		Software and Web applications security
	Strong system security programming skills	Applied cryptography
SGM/SSG artificial intelligence developer or programmer	Strong knowledge in artificial intelligence	Artificial intelligence
		Smart systems
	Strong programming skills in artificial intelligence	Smart autonomous robots
		Advanced mobile programming
		Smart agents

society.

The obtained research outcomes and findings enabled us to formulate the main expected evolution and development tendencies in the SGM and the SGG areas; they include but are not limited to:

- **An effective fusion of smart technology and smart systems with gamification techniques and serious games will be based on adding "smart" features**

to SG, gamification and gamified applications. The new smart features of the SSG and the SGM—adapting, sensing, inferring, learning, anticipating, self-organizing—will make users, environment, processes, activities, solutions and outcomes smarter and more efficient [15, 33].

- **The SGM and the SSG will evolve to "smart" tools to help users to solve "serious" problems**. This is because the SGM and the SGG will actively use sophisticated visualization techniques, principles and technologies of computer and video games, and smart systems and smart technology [1]. The SGM and the SSG will help users to be focused on actual real-world scenarios and situations, apply different variables to various potential solutions and test those solutions, and change/improve/update their skills and behavior [34].
- **The SGM and the SGG analytics will help entire organizations/corporations**. They will help to (a) interpret and process massive data produced by complex corporate computer information, manufacturing, security/safety monitoring, and other systems, (b) apply these data to make smart (intelligent) decisions that minimize possible risks, (c) present essential findings and outcomes in such a simplified way that even non-expert can understand it, (d) optimize gamification techniques in order to influence user productivity, effectiveness, motivation, behavior, invention abilities, etc. [27, 28, 35].
- **The SGM and the SSG will evolve to "smart" tools to significantly increase user engagement**. According to [36], "… 21 % of software development project initiatives fail due to poor levels of user engagement". The key components of user smarter engagement are: (a) exploration (be curious, view, search, collect, analyze, summarize, generalize, propose, investigate, innovate, etc.), (b) compete (challenge, pass, win, beat, train, learn, etc.), (c) collaborate (crowdsourcing, share, work as a team, help, exchange, etc.), (d) express (be creative, select, customize, design, showoff, etc.), (e) be smart (sense, adapt, infer, conclude/deduce, learn, anticipate, self-organize, self-sustain, self-re-organize, etc.) [26].
- **Active implementation and use of the SGM and the SSG will provide businesses and companies with significant benefits**. Those benefits may include but are not limited to (a) improving performance, productivity and effectiveness of entire team and individual team members, (b) enjoyable quality training and the acquisition of new knowledge and skills, (c) energizing employees through smarter wellness and health initiatives and activities, (d) harnessing and leveraging the insight of customers, business partners, (e) engaging customers as part of a long term relationship development strategy, (f) innovating through the collective insights of crowd sourcing and the Internet of Things (IoT) [28, 35].
- **The SGM and the SSG will amplify worker's positive psychology**. The SGM and the SGG will strengthen and extend the PERMA concepts [26] including (a) positive emotions (experiencing joy, pleasure, fun, safety, etc.), (b) engagement (being constantly involved in activities), (c) relationships (enjoyable/supportive interactions with others), (d) meaning (creating a purposeful narrative), and (e) accomplishment (achieving goals, following core values, etc.).

- **Active fusion of the SGM, the SSG, and mobile, social, and virtual collaboration platforms**. The SGM and the SGG will be strongly integrated with new generations of mobile, social, and virtual collaboration systems and technical platforms.

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Chapter 3
Fusion of Secure IPsec-Based Virtual Private Network, Mobile Computing and Rich Multimedia Technology

Alexander Uskov and Hayk Avagyan

Abstract An application of IPsec stack of data exchange protocols in virtual private networks proved to be one of the most reliable and efficient security technologies to provide data protection, confidentiality, integrity, authentication, and access control in computer networks. This chapter presents the outcomes of multi-aspect research project aimed to design and develop IPsec-based mobile virtual private network environments for highly effective, in terms of both security and performance, communications in Web-based rich multimedia systems, including conceptual, design, architectural, and performance modeling of those systems.

Keywords IPsec protocols · Virtual private network technology · Mobile computing · Rich multimedia systems and technology

3.1 Introduction

The increasing mobility of data in corporate or business environments, a fast proliferation of mobile Web, cloud computing and software-as-a-service technology, rapid adoption of "bring your own device" approach, exponential use of video and rich multimedia technology, and widespread diversification of end user devices and technical platforms create significant convenience for corporations, businesses and companies. Advanced Web-Based Rich MultiMedia (WBRMM) systems provide mobile content developers and users with remarkable convenience because of active use of mobile devices, technology and Web, and multiple types of available Rich MultiMedia (RMM) such as:

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- Static text.
- Dynamic textual communications technologies (text messaging, discussion forums, bulletin boards, etc.).
- Audio (pre-recorded audio, audio-conferencing, etc.).
- Dynamic graphics (pre-recorded video, animation, real-time time simulation, video conferencing, recorded computer screen technology, etc.).
- Static graphics (pictures, photos, charts, PPT slides, etc.).

At the same time, those tendencies considerably increase opportunities for information security breaches, new highly sophisticated types of computer attacks, wide distribution of malware and software applications with exploits, and, therefore, significantly decrease the level of security of confidential data transfer and use in computer networks.

The effective integration of IPsec stack of data exchange protocols (IPsec) and Mobile Virtual Private Network (MVPN) security technology is considered to be one of the most reliable security technologies to provide data protection, confidentiality, integrity, authentication, and access control in mobile computer environments.

The rest of this chapter consists of the following parts. Section 3.2 provides basic data and concepts of IPsec-based networks and Web-based rich multimedia systems. In Sect. 3.3, the authors present the developed MVPN's conceptual models, their sets and elements, legal and illegal access functions to the MVPN, information security space model, and the MVPN design methodology that is heavily based on customer requirements to the MVPN's performance, security and cost. In Sect. 3.4, ciphers and modes of cipher operation using a proposed notation and definitions are described. In Sect. 3.5, the technical specifications of real-world practical research and testing environment used as well as summaries of obtained performance benchmarking results for ciphers and modes in IPsec MVPNs are discussed. Finally, conclusions, recommendations and future steps in this research project on fusion of software and network security, mobile computing and multimedia technology are given in Sect. 3.6.

3.2 State-of-the-Art

Section 3.2.1 provides information about mobile devices and mobile data traffic in 2010–2018. Modern Web-based rich multimedia systems are discussed in Sect. 3.2.2. Section 3.2.3 provides security concerns in Web-based systems. The IPsec-based virtual private networks are shortly discussed in Sect. 3.2.4. Research project goal and objectives are situated in Sect. 3.2.5.

3.2.1 Mobile Devices, BYOD and Rich Multimedia Data Traffic, 2010–2018

Mobile Connected Devices. In accordance with 2014 report by Cisco [1], "by the end of 2014, the number of mobile-connected devices will exceed the number of people on earth, and by 2018 there will be nearly 1.4 mobile devices per capita. There will be over 10 billion mobile-connected devices by 2018, including machine-to-machine (M2M) modules—exceeding the world's population at that time (7.6 billion)".

Mobile Data Traffic. According to 2013 report by Ericsson [2], "…mobile data traffic is expected to grow with a CAGR of around 50 % (2012–2018), driven mainly by video. This will result in growth of around 12 times by the end of 2018. Video traffic in mobile networks is expected to grow by around 60 % annually through 2018" (Fig. 3.1).

The world mobile data traffic is estimated to be about 14.0 EB/month in 2018; however, in 2012 it was about 1.2 EB/month, and in 2011—0.6 EB/month. The share of mobile data traffic by application type in 2018 is expected to be as follows (with actual 2010 data given in brackets):

- Video—46 % (31 %).
- Web browsing—10 % (14 %).
- Social networking—9 % (10 %).
- Software download and update—7 % (9 %).
- Encrypted—6 % (5 %).
- File sharing—4 % (8 %).
- Audio—2 % (2 %).
- Other—16 % (21 %).

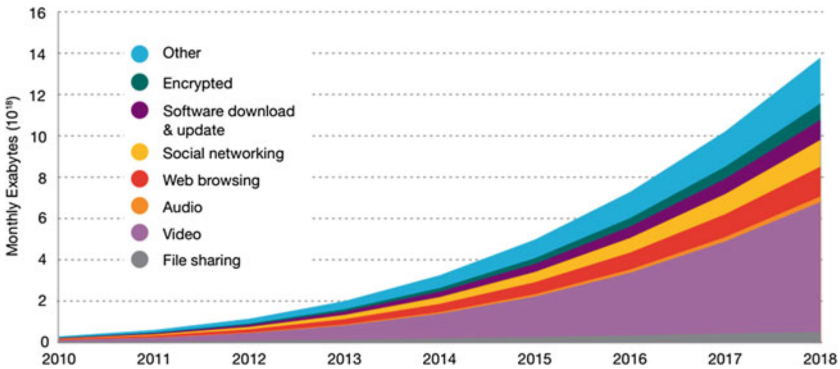

Fig. 3.1 Mobile data traffic by application type, 2010–2018

Also, it is expected that in 2018 the world's population coverage by mobile networks will be as follows (with 2012 actual data given in brackets) [2]:

- GSM/EDGE technology: >90 % (>85 % in 2012), where GSM—Global System for Mobile communications, EDGE—Enhanced Data rates for Global Evolution.
- WCDMA/HSPA technology: >85 % (55 %), where WCDMA—Wideband Code Division Multiple Access, HSPA—High Speed Packet Access.
- LTE technology: 60 % (10 %), where LTE—Long-Term Evolution.

"**Bring Your Own Device**" **Approach**. In accordance with 2013 report by Citrix cloud computing company, "In 2014, BYOD adoption will be largely focused on smartphones (50 % of all users will use this technology), tablets (54 %) and desktops/laptops (25 %). … The growth of mobile devices and applications is largely driven by employees' desire to be more productive. As a result, IT organizations are supporting a wide variety of important applications to support mobility: 90 % of organizations support mobile email, calendaring and contacts' systems, 52 %—line of business mobile apps, 48 %—enterprise file sync and share, 39 %—collaboration tools, 36 %—secure browsers, 35 %—SharePoint access, 21 %—Web conferencing. … In 2014, 42 % of corporate respondents expect to manage 100+ mobile apps, with 21 % of those respondents expecting to manage 1000+ mobile apps" [3].

3.2.2 Modern Web-Based Rich Multimedia Systems

Modern advanced WBRMM systems incorporate mobile computing, streaming, and rich multimedia technologies, and, as a result, provide mobile RMM content developers with an opportunity to quickly create a complex webified RMM data (with integration of text, PPT slides, charts, video, audio, computer animation/simulation) and deliver (stream) data to the end user. For example, one of the first advanced WBRMM systems—the *InterLabs* system—was designed and developed as a part of the National Science Foundation (NSF) grants ## 9950029 and 0409615 [4–7].

Using the developed-by-co-author *ContentCreator* tool of the InterLabs system in Developer mode (Fig. 3.2) [6, 7], the RMM content developer can:

- Create various RMM components (such as video lectures, computer screen).
- Synchronize the RMM components (for example, audio, video, narrated computer exercises based on computer screen capturing technology, computer simulation and/or animation, etc.).
- Synchronize various RMM files.
- Webify the developed RMM content.
- Compress and code the RMM content into ready-to-be-streamed files.
- Upload the developed WBRMM files onto a streaming server.

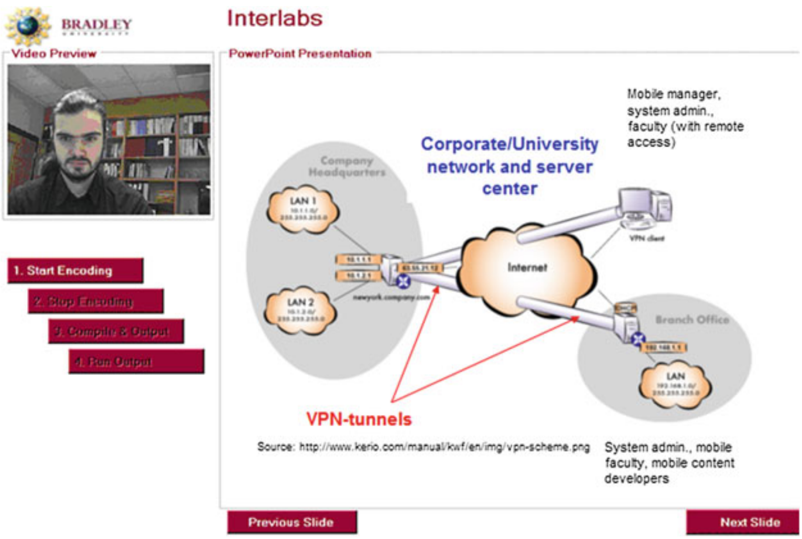

Fig. 3.2 The *Development* mode using the *ContentCreator* tool of the *InterLabs* WBRMM system

As a result, the end users from all over the world are able to play developed and streamed RMM content. The graphic user interface of the *InterLabs* WBRMM system in *User* mode is presented on Fig. 3.3 [6, 7].

The other software tools for video capturing, editing, and its using in WBRMM systems include Camtasia Studio, LiteCam, DebutVideo Capture Software, RipTiger, Screencast-O-Matic, HyperCam, Webcam Video Capture, CamStudio [8].

3.2.3 Security Concerns in Web-Based Systems

Despite the obvious significant achievements in the WBRMM systems' design and development, low levels of security in communications and confidential RMM data files' transfer over public Internet, mobile Web, and mobile networks is still a decisive obstacle for wide and active use of the WBRMM systems by geographically dispersed teams in industry, businesses, and companies.

In accordance with 2014 report by Cenzic [9], "The Web application layer continues to be a soft target with increasing cyber-attacks. 96 % of all applications tested in 2013 have one or more serious security vulnerabilities. The median number of vulnerabilities per app has elevated to 14 (in 2013) from 13 (in 2012). … Privacy Violation and Excessive Privileges appear in over 80 % of mobile apps. … The most frequently found vulnerabilities in Web applications tested are: Cross Site Scripting (XSS) (25 %), information leakage (23 %), authentication and authorization (15 %), session management (13 %), SQL injection (7 %), Cross Site

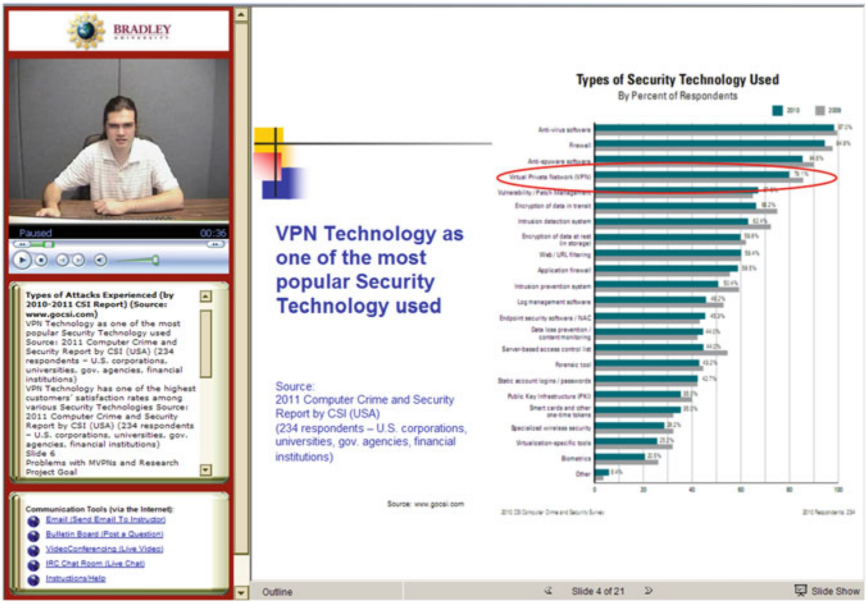

Fig. 3.3 The *User* mode of the *InterLabs* system with frames for video and audio, webified VCR buttons, list of webified informational components available, controls for communication technologies available (email, bulletin board, chat, whiteboard collaboration, video-conferencing, audio-conferencing, etc.), main frame to display the RMM components such as PPT slides, static graphics, webified animation and simulation

Request Forgery (CSRF) (6 %), and other (11 %) round out the list of the total vulnerabilities." The relative share of vulnerabilities found in Web applications tested in 2011–2013 is given on Fig. 3.4 (the sum equals to 100 %) [9].

The identified security concerns in Web applications stimulated an active research on effective fusion of software and network security technology, mobile computing, and the RMM technology in the WBRMM systems.

The proposed approach to solve this problem is based on active utilization of Virtual Private Network (VPN) technology—one of the most reliable technologies to provide data protection, confidentiality, integrity, data origin authentication, replay protection, and access control; this complex technology is also recommended by the National Institute of Standards and Technology, USA [10].

3.2.4 *IPsec-Based Mobile Virtual Private Networks (MVPNs)*

Mobile VPN. The VPNs are created by using tunneling, authentication, and encryption to provide a virtual (hidden) secure channel—a VPN tunnel inside a public network and/or the Internet. A Mobile VPN (MVPN) is a network

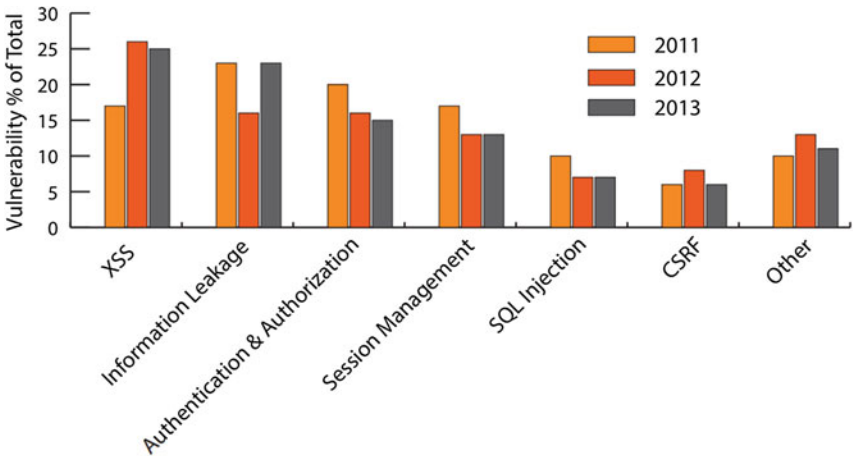

Fig. 3.4 Web application vulnerabilities found trends

configuration, in which mobile devices access the VPN while moving from one geographic location to another one. The key aspect of the MVPN design, development and implementation is a set of protocols and mechanisms that use dynamic IPsec-based tunnels to support user mobility and security [11–15].

IPsec Stack of Protocols (**IPsec**). The IPsec is a framework of open standards for ensuring private communications over public Internet Protocol (IP) based networks. The IPsec architecture [16] includes:

- The IPsec databases such as Security Policy Database (SPD), Security Associations Database (SAD), Peer Authorization Database (PAD).
- Security Associations (SAs) with security parameter index SPI, the IP destination address, and security protocol ID—AH or ESP, as parameters.
- Security protocols such as IP Authentication Header (AH) [17] and IP Encapsulated Security Payload (ESP) [18].
- Cryptographic algorithms for encryption (AES, DES, 3DES, RC5, IDEA, CAST, etc.) and authentication (HMAC, SHAs, MD5, etc.).
- Software associations and key management protocols (IKEv2) [19].

Currently, the vast majority of the MVPNs solutions are based on software-based VPN-tunnels, network layer (layer 3) of the Open Systems Interconnection (OSI) Model, and IPsec; as a result, below we will consider only IPsec-based MVPNs.

3.2.5 Research Project Goal and Objectives

The ultimate goal of this multi-aspect research project is to develop conceptual models and design methodology that will enable mobile network managers and/or system administrators to design and create highly effective MVPN solutions for various types of users, who work with the RMM data and/or the WBRMM systems, and require a secure transfer of the RMM data over the public Internet. In other words, this project is aimed at smooth fusion on highly secure IPsec-based VPN technology, mobile computing, and the WBRMM systems and streaming technology for secure transfer of the RMM data in terms of rapid design and development of IPsec-based MVPNs.

In order to achieve project's goal, the following research objectives must be achieved:

- Create a conceptual model of the MVPN.
- Create a conceptual model of information security space of the MVPN.
- Identify the elements of proposed conceptual models.
- Create a design methodology that will enable the MVPN manager or system administrator to generate specific design solutions for information security of the MVPNs based on various possible requirements, for example, level of security, level of performance, level of total design cost, etc.
- Create an architectural model of the MVPN.
- Create and analyze practical design solutions for different types of the MVPN users.
- Analyze efficiency of encryption algorithms—a central part to secure IPsec-based MVPN—on test RMM data sets of significantly different sizes.
- Make recommendations for the MVPN managers or system administrators, who must design, develop, implement, and maintain secure and high performance networked environments.

3.3 MVPN: Conceptual Models and Information Security Space

Section 3.3.1 provides a Conceptual Model of the MVPN (CM-MVPN). Sets and elements of the CM-MVPN are pointed in Sect. 3.3.2 while legal and illegal access functions of the CM-MVPN are situated in Sect. 3.3.3. Issues of information security space model are discussed in Sect. 3.3.4. Section 3.3.5 provides a design methodology of the MVPN. Examples of the MVPN design solutions are given in Sect. 3.3.6. Architectural model of IPsec MVPN-based WBRMM system is represented in Sect. 3.3.7.

3.3.1 Conceptual Model of Mobile Virtual Private Network (CM-MVPN Model)

The Conceptual Model of MVPN (CM-MVPN) is described below based on notation introduced in [20].

Definition 1: Mobile Virtual Private Network
Mobile virtual private network is described as *n*-tuple of *n* elements, which can be chosen from following sets from Eq. 3.1, where:

– *O* is a set of all objects in organization's network (desktop computers, mobile devices, servers, routers, switches, etc.),
– *S* is a set of all subjects (users) in organization' network including a subset of Users-human beings (U) and a subset of users-SoftWare Applications (SWA),
– *R* is a set of all legal access functions of subjects *S* to objects *O* in organization's mobile network, for example, read, copy, modify functions,
– *AP* is a set of the MVPN architectural models,
– *SH* is a set of software/hardware solutions in the MVPN,
– *TP* is a set of the MVPN topology models,
– *TECH* is a set of technologies used in the MVPN,
– *TS* is a set of secure and trusted the MVPNs,
– *TUN* is a set of the MPVN's tunnel modes,
– *YP* is a set of 7 levels in the OSI model,
– *OS* is a set of MVPN operating systems' models,
– *AA* is a set of authentication algorithms,
– *AM* is a set of authentication methods,
– *AC* is a set of encryption algorithms (ciphers),
– *OPER* is a set of cipher operation modes,
– *PKA* is a set of public key cryptographic algorithms,
– *SP* is a set of security protocols,
– *MOD* is a set of the MVPN's operation modes,
– *AK* is a set of security associations and key management techniques,
– *CT* is a set of the MVPN's connectivity modes,
– *AV* is a set of the MVPN's availability levels,
– *PAR* is a set of parameters for various security algorithms to be used in the MVPN.

$$\begin{aligned} CM\text{-}MVPN = \langle &\{O\},\{S\},\{R\},\{AP\},\{SH\},\{TP\},\{TECH\},\{TS\},\\ &\{TUN\},\{YP\},\{OS\},\{AA\},\{AM\},\{AC\},\{OPER\},\\ &\{PKA\},\{SP\},\{MOD\},\{AK\},\{CT\},\{AV\},\{PAR\}\rangle \end{aligned} \tag{3.1}$$

3.3.2 CM-MVPN: Sets and Elements

The sets in the CM-MVPN model (Eq. 3.1) include but are not limited to the following ones [11–21]:

{*AP*} = {1 = internal MVPN model (intranet MVPN), 2 = external MVPN model (extranet MVPN), 3 = a combination of particular models, etc.}

{*SH*} = {1 = software-based MVPN (with software clients), 2 = hardware-based MVPN (with hardware clients), 3 = MVPN-based on specialized software/hardware embedded equipment, 4 = a combination of particular models, etc.}

{*TP*} = {1 = MPVN gateways in parallel with the firewalls, 2 = MPVN gateways behind the firewalls, etc.}

{*TECH*} = {1 = IPsec, 2 = Layer 2 Forwarding (L2F) protocol, 3 = Point-to-Point Tunneling Protocol (PPTP), 4 = L2TPv3, 5 = Layer 2 Tunneling Protocol—versions 2 and 3 (L2TPv2/ L2TPv3), 6 = Security Socket Layer /Transport Layer Security (SSL/TLS) protocols and technologies, 7 = a combination of particular protocols and technologies, etc.}

{*TS*} = {1 = secure MVPN, 2 = trusted MVPN}

{*TUN*} = {1 = compulsory tunnel mode (with L2F, PPTP, or L2TPv2/L2TPv3 protocols), 2 = voluntary tunnel mode (with IPsec, PPTP, L2TPv2/ L2TPv3, or SSL/TLS protocols), 3 = a combination of particular tunnel modes}

{*YP*} = {1 = physical layer, 2 = data link layer, 3 = network layer, 4 = transport layer, 5 = session layer, 6 = presentation layer, 7 = application layer in the OSI model}

{*OS*} = {1 = mobile device on an operating system—VPN gateway/concentrator on B operating system; a note: this set uses a particular type of operating system as a parameter; as a result, parameters A and B above may have the following values: 1 = Windows OS, 2 = UNIX/Linux OS, 3 = Mac OS, 4 = Android OS, 5 = iOS, etc.)

{*AA*} = {hash algorithms (or, integrity algorithms): 1 = MD5, 2 = SHA-1, 3 = SHA-2, 4 = SHA-256, 5 = SHA-384, 6 = SHA-512, etc.; Message Authentication Code (MAC) And Hashed Message Authentication Code (HMAC) algorithms: 21 = HMAC(MD5), 22 = HMAC (SHA-1), 23 = HMAC(SHA-2), 24 = HMAC(SHA-256), etc.}

{*AM*} = {1 = pre-shared key, 2 = Kerberos, 3 = X.509 standard certificates, 4 = Elliptic Curve Digital Signature Algorithm (ECDSA) with parameters, etc.}

{*AC*} = {block ciphers with various parameters, for example, size of secret key length or data block size: 1 = AES ciphers, 2 = RC6 ciphers, 3 = RC5 ciphers, 4 = TwoFish ciphers, 5 = DES ciphers, 6 = DES/3DES (or, TripleDES) ciphers, 7 = IDEA ciphers, 8 = CAST ciphers, 9 = Camellia ciphers, etc.}

{*OPER*} = {1 = Electronic Codebook (ECB) cipher mode of operation, 2 = Cipher-Block Chaining (CBC), 3 = Cipher FeedBack (CFB), 4 = Output FeedBack (OFB), 5 = Counter Mode (CTR), 6 = counter mode with CBC-MAC (CCM), 7 = Galois/Counter Mode (GCM), 8 = EAX, etc.}

{*PKA*} = {1 = Diffie-Hellman, 2 = Rivest, Shamir, and Addlemen (RSA), 3 = Digital Signature Algorithm (DSA), 4 = El-Gamal, etc.}

{*SP*} = {1 = authentication header AH, 2 = Encapsulation Security Payload (ESP), 3 = a combined use of AH and ESP, etc.}

{*MOD*} = {1 = tunnel mode, 2 = transport model}

{*AK*} = {1 = manual management, 2 = automated management with Internet key exchange protocol—version 2 (IKEv2) [15], etc.}

{*CT*} = {1 = connection via AP Wi-Fi; 2 = connection via 2G; 3 = connection via 3G; 4 = connection via 4G; etc.}

{*AV*} = {1 = load balancing of the MVPN connections over a number of the VPN gateways at the same central site, 2 = failover between a number of the VPN gateways at the same central site using the Virtual Router Redundancy Protocol (VRRP), 3 = the use of backup the VPN gateways at geographically dispersed the VPN gateways at a number of sites, etc.}

{*PAR*} = {set may contain hundreds of elements-parameters used by various MVPN models, protocols, algorithms, ciphers, and technologies. For example, one of the elements—{*par* = 2} is that IKEv2 header's *Next_Payload* component; it alone has the following parameters for a payload type [15]: SA, key exchange, identification—initiator, identification—responder, certificate, certificate request, authentication, nonce, notify, delete, vendor ID, traffic selector—initiator, traffic selector—responder, encrypted, configuration, and extensible authentication. Almost each of these parameters has its own sets of sub-parameters; as a result, a comprehensive description of elements in the *PAR* set is omitted}.

3.3.3 CM-MVPN: Legal and Illegal Access Functions

Based on the proposed CM-MVPN model (Eq. 3.1), let us define access functions in the CM-MVPN, in general, and, particularly, sets of legal and illegal access functions.

Definition 2: Access Functions in MVPN

Let $t = 1, 2, \ldots$ be a discrete time, *Ot* is a collection of elements from sets in the CM-MVPN tuple at time, and *Et* is a set of relations between these elements at time *t*. In this case, an access function is a pair of $Gt = (Ot, Et)$.

Access function $Gt = (Ot, Et)$ is a graph of access functions to MPVN at time *t*, where *Ot* is a graph vertices, $Et \subset \langle Ot\ x, Ot\ y \rangle$, *Et* is a set of graph edges (in this case, each edge corresponds to an access function in the MVPN at time *t*).

Let us assume that *Go* is an access function to the MVPN at time $t = 0$, and *Gp* is a set of all possible access functions or all possible sequences of graph edges (in this case, each possible sequence corresponds to a particular operation *s* of the MVPN in the set of all possible operations *S*).

The *Gp* set contains two subsets, called *Gl* is a set of legal access functions or particular operations in the MVPN and *Gn* is a set of illegal access functions or particular operations in the MVPN so that $Gp = Gl \cup Gn$, $Gl \cap Gn = \emptyset$.

3.3.4 Information Security Space of MVPN (IS-MVPN Model)

Based on the proposed CM-MVPN model (Eq. 3.1) and its defined sets, one can describe a conceptual model of the MVPN's Information Security space—IS-MVPN model as the Cartesian product over identified sets provided by Eq. 3.2.

$$\begin{aligned} IS{-}MVPN = {} & O \times S \times R \times AP \times SH \times TP \times TECH \times TS \times TUN \times YP \\ & \times OS \times AA \times AM \times AC \times OPER \times PKA \times SP \times MOD \\ & \times AK \times CT \times AV \times PAR \end{aligned} \tag{3.2}$$

A goal of a MVPN's information security is to assure that a particular access function $Gt \in Gl$ in the IS-MVPN space (Eq. 3.2).

3.3.5 Design Methodology of MVPN (DM-MVPN Model)

The conceptual model CM-MVPN (Eq. 3.1) provides information security managers and/or network/system administrators with a systematic approach to generate various possible design solutions for the MVPN or, in other words, to apply a design methodology for the MVPN—the DM-MVPN model provided by Eq. 3.3.

$$\begin{aligned} DM{-}MVPN = {} & \langle \{AP\}, \{SH\}, \{TP\}, \{TECH\}, \{ST\}, \{TUN\}, \{YP\}, \\ & \{OS\}, \{AA\}, \{AM\}, \{AC\}, \{OPER\}, \{PKA\}, \{SP\}, \\ & \{MOD\}, \{AK\}, \{CT\}, \{AV\}, \{PAR\} \rangle \end{aligned} \tag{3.3}$$

The DM-MVPN models' tabular form is presented in Table 3.1; it contains the following components:

- In column # 1: a set of design procedures on each design stage.
- In column # 2: a list of available design solutions for each design stage.
- In column # 3: a global optimization procedure that, in general case, may use one or many optimization criteria, which are determined by information security manager and/or network/system administrator, for example: *SEC* is a level of the MVPN security, *PERF* is a level of the MVPN performance, *COST* is a total design and development cost of the MVPN.

The design solutions in *SH*, *TECH*, *TS*, *YP*, and *AK* sets in Table 3.1 are pre-selected specifically for secure IPsec-based MVPNs with software-based clients. This is because currently the vast majority of the MVPNs solutions are based on software-based VPN-tunnels, network layer (layer 3) of OSI Model, and IPsec; as a result, below we will consider only secure IPsec-based MVPNs with software clients.

Upon completion of design procedures (column # 2 in Table 3.1) by selection of an appropriate MVPN design solution from a list of possible design solutions (in column # 3 of Table 3.1), the design methodology DM-MVPN will generate a set of possible design methods—set $\{M\}$-to create IPsec-based MVPN design solutions provided by Eq. 3.4, where *Ml* is a subset of legal MVPN design methods, *Mn* is a subset of illegal MVPN design methods, *Mr* is a subset of recommended MVPN design methods.

$$\{M\} = \{\{Ml\}, \{Mn\}, \{Mr\}\} \tag{3.4}$$

The relationships between these subsets are described as mentioned in Eq. 3.5.

$$M = Ml \cup Mn \quad Ml \cap Mn = \emptyset \quad Mr \subseteq Mr \quad Mr \cap Mn = \emptyset \tag{3.5}$$

The elements in *Mr* set will be finalized upon completion of optimization procedures (column 4 in Table 3.1). Global optimization procedure *OPTIM* in the DM-MVPN can use different levels of local optimization criteria *SECopt*, *PERFopt*, and *COSTopt*; those levels are identified and/or specified by the MPVN administrator, for example:

- *SECopt* will regulate the required level of security *SEC* of data transmission in MVPN-tunnels, for example, *SECopt* = *LOW* (means low level of security is required by security administrator), *SECopt* = *MED* (satisfactory level of security is required), *SECopt* = *HPO* (highest possible level of security is required).
- *PERFopt* will regulate the required level of performance *PERF* of MVPN-tunnels: the available options are *PERFopt* = *LOW*, *PERFopt* = *MED*, *PERFopt* = *HPO*.
- *COSTopt* will regulate the required level of total cost *COST* of MVPN design and development solution: the available options are *COSTopt* = *LP* (lowest possible level of total cost), *COSTopt* = *MED*, *COSTopt* = *HLI* (high level but with upper limit).

Table 3.1 IPsec-based MVPN design model DM-MVPN

# of design stage (1)	MPVN design procedure (2)	MPVN design solutions—available and/or pre-selected (3)	MVPN optimization procedures (4)
1	Select an element from {*AP*}	*AP1*, *AP2*, *AP3*, ...	Based on organizations' needs and/or *COST*
2	Select an element from {*SH*}	*SH* = 1 (i.e. software clients)	
3	Select an element from {*TP*}	*TP1*, *TP2*	*SEC*, *PERF*, *COST*
4	Select an element from {*TECH*}	*TECH* = 1 (i.e. IPsec)	
5	Select an element from {*TS*}	*TS* = 1 (i.e. secure MVPN)	
6	Select a element from {*YP*}	*YP* = 3 (i.e. network layer)	
7	Select a element from {*OS*}	*OS1*, *OS2*, *OS3*, *OS4*, ...	Based on mobile device's *OS*
8	Select specific element(s) from {*AA*}; if necessary, select elements {*par*} from {*PAR*}	*AA1*, *AA2*, *AA3*, ...; *select* {*par*} *from* {*PAR*}	*SEC*, *PERF*
9	Select specific element(s) from {*AM*}; if necessary, select elements {*par*} from {*PAR*}	*AM1*, *AM2*, *AM3*, ...; *select* {*par*} *from* {*PAR*}	*SEC*, *PERF*
10	Select specific element(s) from {*AC*}; if necessary, select elements {*par*} from {*PAR*}	*AC1*, *AC2*, *AC3*, ...; *select* {*par*} *from* {*PAR*}	*SEC*, *PERF*
11	Select specific element(s) from {*OPER*}; if necessary, select elements {*par*} from {*PAR*}	*OPER1*, *OPER2*, *OPER3*, ...; *select* {*par*} *from* {*PAR*}	*SEC*, *PERF*
12	Select specific element(s) from {*PKA*}; if necessary, select elements {*par*} from {*PAR*}	*PKA1*, *PKA2*, *PKA3*, ...; *select* {*par*} *from* {*PAR*}	*SEC*, *PERF*
13	Select specific element(s) from {*SP*}; if necessary, select elements {*par*} from {*PAR*}	*SP1*, *SP2*, *SP3*, ...; *select* {*par*} *from* {*PAR*}	*SEC*, *PERF*
14	Select an specific element from {*MOD*}; if necessary, select elements {*par*} from {*PAR*}	*MOD1*, *MOD2*; *select* {*par*} *from* {*PAR*}	*PERF*, *SEC*

(continued)

Table 3.1 (continued)

# of design stage (1)	MPVN design procedure (2)	MPVN design solutions—available and/or pre-selected (3)	MVPN optimization procedures (4)
15	Select an specific element from {*AK*}; if necessary, select elements {*par*} from {*PAR*}	*AK* = 2 (i.e. IKEv2)	
16	Select an specific element from {*CT*}; if necessary, select elements {*par*} from {*PAR*}	*CT1*, *CT2*, *CT3*, …; *select* {*par*} *from* {*PAR*}	Based on mobile user needs
17	Select an specific element from {*AV*}; if necessary, select elements {*par*} from {*PAR*}	*AV1*, *AV2*, *AV3*; *select* {*par*} *from* {*PAR*}	*COST*, *SEC*, *PERF*

The CM-MVPN (Eq. 3.1), the IS-MVPN (Eq. 3.2), and the DM-MVPN (Eq. 3.3) conceptual models clearly demonstrate that the MVPN's effectiveness—performance, security and cost—for integrated WBRMM systems significantly depends on effectiveness of encryption algorithms (or ciphers) {*AC*} and modes of cipher operation (or modes) {*OPER*}. As a result, it is necessary to carefully investigate both performance and security of most popular ciphers and modes in order to recommend the best ones to be used in the MVPNs for the WBRMM systems—the research outcomes are presented in Sects. 3.4 and 3.5.

3.3.6 DM-MVPN Model: Examples of Legal and Illegal MVPN Design Solutions

Several specific examples of design methods {*M*} are described below. Those examples are relevant to a hypothetical training organization (for example, corporate university or online academy like Microsoft or Cisco academies) that actively uses immersive training/learning, and, therefore, requires its geographically dispersed trainers and/or online learning content developers to quickly create/update rich educational multimedia training content and upload it onto streaming server in a central location using the MVPN.

Example 1 IPsec-based MVPN design solution for a top-level manager or network administrator.

A group of organization's top-level manager(s) or network administrator(s), who should have a remote access from a mobile device to highly confidential organizational data. In this case, the IPsec MVPN design solution *m1* must provide user with highest level of security (*SECopt* = *HPO*), satisfactory requirements for

MVPN's performance (*PERFopt* = *MED*), and cost (*COSTopt* = *MED*) as pointed in Eq. 3.6.

$$\begin{aligned} m1 \in Mr,\ m1 = \{ & AP3,\ CP3(1-4),\ TP5(TP1-TP3),\ \ YP = 3, P = 1,\ MOD = 2, \\ & AA = 1, OPER = 2,\ CT = 4,\ AC - S1(PAR12 = 5,\ PAR1 = 2), \\ & AC - H3(PAR7 = 4),\ AC - P3(PAR6 = 4), AC - X1,\ \ PAR = \{PAR1 = 2, \\ & PAR2 = 2, PAR3 = 1,\ PAR4 = \{1,\ 2\},\ PAR5 = 1,\ \ PAR9 = 3, \\ & PAR10 = 2,\ PAR11 = 4,\ PAR12 = 4\} \end{aligned} \tag{3.6}$$

In this case, *OPTIM* = *SUM*(*SECopt* = *HPO*; *PERFopt* = *MED*; *COSTopt* = *MED*).

Example 2 IPsec-based MVPN design solution for a mobile and remote developer of rich multimedia training content.

Mobile developers of multimedia training content for corporate immersive training/learning also should use a specific type of the IPsec MVPN design solution. It can be described by the below MVPN design method (Eq. 3.7).

$$\begin{aligned} m2 \in Mr,\ m2 = \{ & AP3,\ CP3(1-1),\ TP5(TP1-TP3),\ \ YP = 3, P = 1,\ MOD = 2, \\ & AA = 1, OPER = 2,\ CT = 1,\ AC - S1(PAR12 = 4,\ PAR1 = 2), \\ & AC - H1(PAR7 = 3),\ AC - P2, PAR = \{PAR1 = 2,\ PAR2 = 1, \\ & PAR3 = 1, PAR4 = 1,\ PAR5 = 1,\ PAR9 = 1,\ \ PAR10 = 1, \\ & PAR11 = 10,\ PAR12 = 4\} \end{aligned} \tag{3.7}$$

In this case, *OPTIM* = *SUM*(*SECopt* = *MED*; *PERFopt* = *HPO*; *COSTopt* = *LP*).

This design method provides a maximal performance of the MVPN (*PERFopt* = *HPO*) and satisfactory requirements for a security (*SECopt* = *MED*) of data transmitted via the MVPN and low total cost (*COSTopt* = *LP*). For example, this design method should be used by a trainer, who videotapes his/her training sessions outside training center and posts them on organization's streaming server(s).

Example 3 Illegal IPsec-based MVPN design solution.

An example of a possible illegal IPsec MVPN design method could be described by Eq. 3.8.

$$\begin{aligned} m3 \in M,\ m3 = \{ & AP3,\ CP3(1-1),\ TP5(TP1-TP3),\ \ YP = 3, P = 1,\ MOD = 2, \\ & AA = 1, OPER = 2,\ CT = 1,\ AC - S3(PAR3 = 4,\ PAR1 = 2), \\ & AC - H1(PAR7 = 3),\ AC - P3(PAR6 = 2), AC - X1, \\ & AR = \ \{PAR1 = 2, PAR2 = 1,\ PAR3 = 1,\ PAR4 = 1,\ \ PAR5 = 1, \\ & PAR9 = 1,\ PAR10 = 1, PAR11 = 10,\ PAR12 = 4\} \end{aligned} \tag{3.8}$$

This design method $m3$ is illegal because in accordance with the selected value $AC\text{-}S3(PAR3 = 4, PAR1 = 2)$ $AC = \{3\}$ it must use the *DES* cipher. However, a selected value $P = \{6\}$ corresponds to the authentication header AH only: it does not support data encryption by itself. As a result, there is a conflict of encryption requirement (use of *DES*) and no encryption capability in *AH*. Conclusion: the described design method $m3$ is illegal one in the IS-MVPN information security space.

3.3.7 Architectural Model of IPsec MVPN-Based WBRMM System

The developed architectural model of the IPsec MVPN-based WBRMM system is given in Fig. 3.5; it clearly shows a complexity of modern WBRMM systems. Modern IPsec MVPN-based WBRMM systems must contain the following major components:

1. Mobile developers of the RMMM content (with various types of mobile devices).
2. The RMM files of different types, including: 2-1—Webified versions of static multimedia files (text, static graphics, PPT slides, etc.); 2-2—audio files; 2-3—video and dynamic graphics files (animation, simulation of processes).
3. Encoding of source RMM files.
4. Compression and mutual synchronization of the RMM files; integration of those files with various communication and collaborative technologies and supporting tools of the WBRMM system.
5. Structurization of integrated RMM data files and their upload onto streaming/Web/data/application/communication servers of the WBRMM system using the MVPN.
6. Streaming/data/Web/communication servers with 6-1—storage units, 6-2—Quality of Service (QoS) on server side, 6-3—encoding of the RMM files using IP, RTP, RTCP, UDP, TCP, RTSP, SIP, and other types of protocols.
7. Secure transfer of the RMM files over the MVPN from servers to the end users.
8. End user's mobile device that provides 8-1—downloading of the RMM files on client side using various data protocols, 8-2—the QoS on client side, 8-3 decoding of the RMM files, 8-4—synchronization of decoded RMM files, and 8-5—visualization of the RMM files.
9. Mobile end users of the RMM content.

The MPVN tunnels are used in processes ## 5 and 7 in Fig. 3.5.

The CM-MVPN (1) and the IS-MVPN (2) conceptual models clearly demonstrate that MVPN's effectiveness—i.e. a combination of performance, security, and cost characteristics—for the WBRMM systems significantly depends on effectiveness of ciphers $\{AC\}$ and modes $\{OPER\}$. As a result, it is necessary to carefully investigate both security and performance characteristics of the most popular ciphers and modes in order to recommend the best ones for active use in the MVPN design model DM-MVPN (Eq. 3.3) for the WBRMM systems; the corresponding research outcomes on cipher' and modes' security and performance are presented in Sects. 3.4 and 3.5.

3.4 Ciphers and Cipher Modes for MVPN

Several popular encryption algorithms (ciphers) and modes of their operation (modes) are described below using basic definitions and notation from [21]. However, these definitions and notation have been significantly adjusted to the

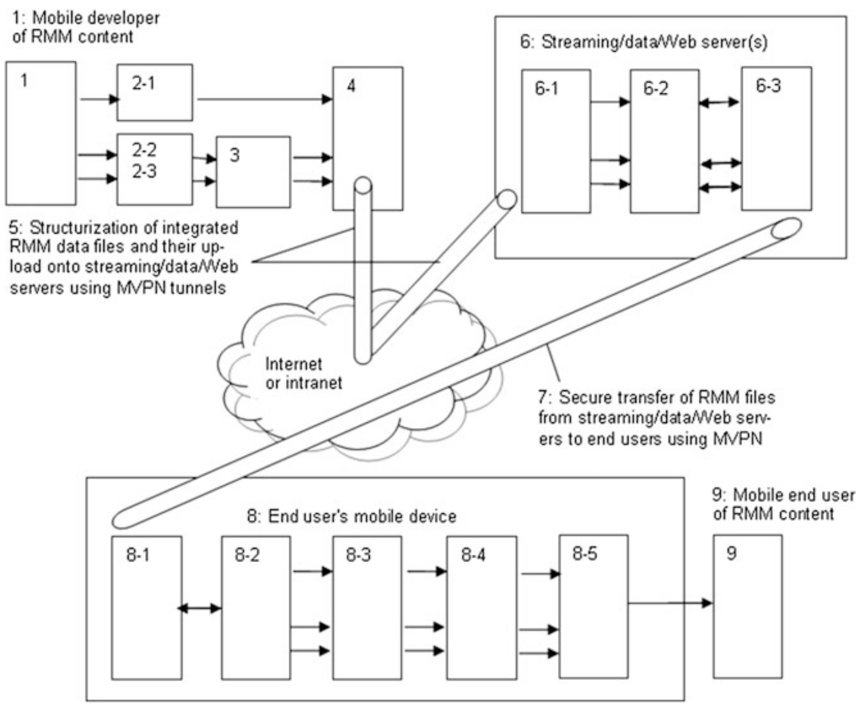

Fig. 3.5 The developed architectural model of IPsec MVPN-based WBRMM system

needs of this research project. The main definitions are situated in Sect. 3.4.1. Two popular ciphers—Data Encryption System (DES) and Advanced Encryption System (AES)—are described in Sect. 3.4.2. Section 3.4.3 includes descriptions of two popular modes of cipher operation—Cipher Block Chain (CBC) and Counter Mode (CTR). Issues of security of ciphers and modes are discussed in Sect. 3.4.4.

3.4.1 Preliminaries

Definition 3: A Cryptosystem [21]

A cryptosystem (or cipher) is a five-tuple $\mathcal{S} = (\mathcal{P}, \mathcal{C}, \mathcal{K}, \varepsilon, \mathcal{D})$, where the following conditions are satisfied:

1. $\mathcal{P}$ is a finite set of possible plaintexts.
2. $\mathcal{C}$ is a finite set of possible ciphertexts.
3. $\mathcal{K}$, the keyspace, is a finite set of possible keys.
4. For each $K \in \mathcal{K}$ there are such an encryption rule $e_K \in \varepsilon$, $e_K : \mathcal{P} \to \mathcal{C}$ and a corresponding decryption rule $d_K \in \mathcal{D}, d_K : \mathcal{C} \to \mathcal{P}$ that for every plaintext element $x \in \mathcal{P}$ the decryption is defined as

$$d_K(e_K(x)) = x.$$

A note: A cryptosystem is called *endomorphic cryptosystem*, if $\mathcal{C} = \mathcal{P}$.

In order to increase cipher's security it is common to combine several encryption schemes, i.e. apply a second cipher to the ciphertext gained after an application of the first one to a plaintext; the resulting combination of application of several consecutive ciphers is called a *product cipher*.

Theorem 1

Suppose $\mathcal{S}_1 = (\mathcal{P}_1, \mathcal{C}_1, \mathcal{K}_1, \varepsilon_1, \mathcal{D}_1)$ *and* $\mathcal{S}_2 = (\mathcal{P}_2, \mathcal{C}_2, \mathcal{K}_2, \varepsilon_2, \mathcal{D}_2)$ *are two ciphers, and* $\mathcal{C}_1 \subseteq \mathcal{P}_2$. *Then a product cipher—a cryptosystem is defined as*

$$\mathcal{S}_1 \times \mathcal{S}_2 = (\mathcal{P}, \mathcal{C}, \mathcal{K}_1 \times \mathcal{K}_2, \varepsilon, \mathcal{D}),$$

where

1. $\mathcal{P} = \mathcal{P}_1$ and $\mathcal{C} = \mathcal{C}_2$.
2. *Key of product cipher is* $K = (K_1, K_2)$, *where* $K \in \mathcal{K}_1$ *and* $K_2 \in \mathcal{K}_2$.
3. *For each* $K = (K_1, K_2)$ *encryption and decryption rules are defined as follows:*

$$e_K(x) = e_{(K_1,K_2)}(x) = e_{K_2}(e_{K_1}(x)),$$
$$d_K(x) = d_{(K_1,K_2)}(x) = d_{K_1}(e_{K_2}(x)).$$

Proof One can see that this definition satisfies all conditions of the Definition 1 above; particularly, for its condition 4 we will have

$$d_{(K_1,K_2)}\big(e_{(K_1,K_2)}(x)\big) = d_{(K_1,K_2)}(e_{K_2}(e_{K_1}(x)))$$
$$= d_{K_1}(d_{K_2}(e_{K_2}(e_{K_1}(x)))) = d_{K_1}(e_{K_1}(x)) = x\ .$$

The vast majority of modern block ciphers are product ciphers, and a commonly used form of a product cipher is an *iterated cipher*. In this case, the initial state ω^0 is defined to be the plaintext x. The encryption of a plaintext is processed through N_r similar *rounds* by using *key schedule* $K = (K^1, \ldots, K^{N_r})$ and *round function* g, which should be defined in advance. In each of N_r rounds, the round function g takes two inputs: (1) a round key K^r, and (2) a current state ω^{r-1}. As a result, the subsequent state is defined as $\omega^r = g(\omega^{r-1},\ K^r)$. Round function g cannot be a random function. To make a decryption possible, the round function g should be *injective* (or one-to-one), if its second argument, i.e. round key, is fixed. This is equivalent to a statement that a function g^{-1} should exist so that $g^{-1}(g(\omega,\ k),\ k) = \omega$ for all ω and k.

Most popular block ciphers such as AES, DES, or 3DES use a spatial type of iterated cipher that is called a *Substitution-Permutation Network* (*SPN*).

Two types of cryptosystems are defined below using the basic notation from [21]; it has been adjusted to the needs of this research project in terms of the SPN definition. □

Definition 4: A Substitution Cipher (Cryptosystem 1)
Let $|\mathcal{P}| < |\mathcal{C}|$ and $\mathcal{K}$ is a set of all possible one-to-one mappings of elements of $\mathcal{P}$ to elements of $\mathcal{C}$. For each mapping $\pi_S \in \mathcal{K}$, $e_{\pi_S}(x) = \pi_S(x)$ and $d_{\pi_S}(x) = {\pi_S}^{-1}(x)$, where ${\pi_S}^{-1}$ is the inverse of π_S.

Definition 5: A Permutation Cipher (Cryptosystem 2)
Let $|\mathcal{P}| = |\mathcal{C}|$, and let $\mathcal{K}$ consists of all permutations of set $\{1,\ldots,m\}$. For every key π_P and plaintext $x = (x_1,\ldots,x_m)$ we define

$$e_{\pi_P}(x_1,\ldots,x_m) = \big(x_{\pi_P(1)},\ldots,x_{\pi_P(m)}\big)$$

and

$$d_{\pi_P}(x_1, \ldots, x_m) = \left(x_{\pi_P{}^{-1}(1)}, \ldots, x_{\pi_P{}^{-1}(m)}\right),$$

where ${\pi_P}^{-1}$ is the inverse of permutation π_P.

In this case, the SPN is defined as follows.

Definition 6: A Substitution-Permutation Network (SPN)
Let l, m and N_r be positive integers. Let π_S: $\{0, 1\}^l \rightarrow \{0, 1\}^l$ be a substitution function, and let π_P: $\{1, \ldots lm\}$ be a permutation function. Let $\mathcal{P} = \mathcal{C} = \{0, 1\}^{lm}$, where lm is a length of data block in a cipher. Let $\mathcal{K} = [0, 1]^{lm^{N_r+1}}$ consist of all possible key schedules, which could be derived from initial key $\mathcal{K}$ using the key scheduling algorithm [21].

For a key schedule $K^1, \ldots, K^{N_r}$ and plaintext x the SPN algorithm is defined as follows:

1. Initial state $\omega^0 \equiv x$.
2. For each round ***r*** except the final round N_r:

   2.1 Apply $\oplus$ bit-by-bit addition modulo 2 (or, XOR operation):

   $$u^r = \omega^{r-1} \oplus K^r.$$

   2.2 Divide u^r into m substrings—each of length l:

   $$u^r = {u^r}_{<1>} \| \ldots \| {u^r}_{<m>}.$$

   2.3 For each substring i apply substitution function π_S:

   $${v^r}_{<i>} = \pi_S({u^r}_{<i>}).$$

   2.4 Define next state ω^r by applying permutation π_P function:

   $$\omega^r = \left(v^r_{\pi_P(1)}, \ldots, v^r_{\pi_P(lm)}\right).$$

3. In the final round N_r perform operations 2.1, 2.2, 2.3 and instead of operation 2.4 perform XOR operation:

   $$y = \omega^{N_r} \oplus K^{N_r+1}.$$

A note: in this case, the substitution function π_S is called the *S-box*.

3.4.2 Encryption Algorithms (Ciphers)

To verify the introduced definitions and notation, two popular ciphers—Data Encryption System (DES) and Advanced Encryption System (AES) are described below.

DES cipher. The DES is a 16 round cipher with 64-bit block length and 56-bit key. In DES cipher each state ω^r is divided into two halves with the same length L^r and R^r.

The round function g is defined as $g(L^{r-1}, R^{r-1}, K^r) = (L^r, R^r)$, where $L^r = R^{r-1}$, $R^r = L^{r-1} \oplus f(R^{r-1}, K^r)$.

The function f does not need to be injective because $L^{r-1} = R^r \oplus f(L^r, K^r)$, $R^{r-1} = L^r$ and it is always invertible (this algorithm is also known as Feistel network).

Before starting encryption rounds it applies *initial permutation* $L^0\, R^0 = \mathbf{IP}(x)$, and after 16 rounds it applies inverse permutation $y = \mathbf{IP}^{-1}\left(R^{16}L^{16}\right)$. The details about function f, initial permutation, and substitution and permutation functions used by f are available at [22].

AES cipher. The AES is a block cipher with 128-bit block length. It can use three different key lengths, specifically 128, 192, 256-bits—they correspond to AES-128, AES-192, and AES-256 ciphers, respectively. Each of these ciphers has a different number of rounds, specifically, 10 rounds for AES-128, 12—for AES-192 and 14—for AES-256.

The AES cipher uses the SPN algorithm as well. After the initial round key addition $\omega^1 = \omega^0 \oplus K^0$, the AES cipher uses round function to transform state ω 10, 12, 14 times, respectively, depending on key length. In each round, with exception of the final round (which is slightly different), the state round function $\omega^r = g(\omega^{r-1}, K^r)$ is composed of four different byte-oriented transformations: (1) byte substitution using a substitution table (S-box), (2) shifting rows of the state array by different offsets, (3) mixing the data within each column of the state array, and (4) adding a round key to the state. The final round does not include mixing [23].

In general case, it is necessary to encrypt original messages that are longer or shorter than cipher's block length. Also, it is not initially clear how many rounds of encryption should be used; for example, as it was mentioned above, the AES cipher may have several options in terms of numbers of rounds to be executed: 10, 12 and 14. These are the main reasons that a block cipher should use a cipher mode of operation (a mode) to overcome the identified problems.

3.4.3 Modes of Cipher Operation

For a verification purpose of the introduced above definitions and notation, three popular modes—Cipher Block Chain (CBC), Counter Mode (CTR), and Galois/Counter Mode (GCM) are described below.

Definition 7: Cipher Block Chain (CBC) Mode of Cipher Operation [24]
Let x is a plaintext and $\boldsymbol{S}$ is some block cipher with block length l. The CBC mode is defined as follows:

1. Break the plaintext to several blocks with length $l\ \ x = (x_1, \ldots, x_m)$.
2. Take *initialization vector* IV = $C_0 = O^l$ where O^n is a string of n O's.
3. Perform XOR operation on a ciphertext of previous block with a plaintext of the next one next and encrypt $S(x_i \oplus C_{i-1}) = C_i$.
4. Obtain the resulting ciphertext $\boldsymbol{C} = C_m$.

Note that if one of x_i parts is changed, then it will affect all subsequent ciphertexts. This means that the CBC mode can be used to produce Message Authentication Code (MAC).

Definition 8: Counter (CTR) Mode of Cipher Operation [24]
Let x be a plaintext and $\boldsymbol{S}$ be a block cipher with block length $\boldsymbol{l}$. In this case, the CTR mode is defined as follows:

1. Break the plaintext to several blocks with length $l\ x = (x_1, \ldots, x_m)$.
2. Choose a counter ***ctr*** which is a bit string with length l.
3. Generate a sequence of bit strings $T_i = ctr + i - 1 mod 2^l$ for $i \geq 1$.
4. Encrypt plaintext blocks by computing $x_i \oplus \mathbf{S}(T_i) = C_i$.
5. Combine resulting ciphertexts together $C = (C_1, \ldots, C_m)$.

A description of the Galois/Counter Mode (GCM), using the introduced definitions and notation, is given in [25].

3.4.4 Security of Ciphers and Modes

A measure of cipher's security is still one of the most debatable problems these days. We follow the recommendations of the ciphers' security analysis by the U.S. National Institute of Standards and Technology [26] with main outcomes as in Table 3.2, where TD is "truncated difference" type of computer attack, SD is "statistical distinguisher" type of attack, RK is "related key" type of attack, ID is "impossible differential" type of attack, NA is "information is not available".

The AES cipher's security. For 128-bit keys, 6 or 7 out of the 10 rounds of the AES have been attacked, the attack on 7 rounds requires nearly the entire codebook (what leads to a very long time period to get a successful attack). For 192-bit keys, 7 out of the 12 rounds have been attacked. For 256-bit keys, 7, 8, or 9 out of the 14 rounds have been attacked. However, the 8th round of attack requires nearly the entire codebook, and the 9th round of an attack requires encryptions under related unknown keys. As a result, the AES cipher offers a very high level of data security: it required 2^224 operations to mount an attack on 9 (with key size = 256) rounds (Table 3.2).

Table 3.2 A summary of reported attacks on reduced-rounds variants of selected ciphers [26]

Cipher, rounds	Rounds (key size)	Type of attack on a cipher	Text size required to effect attack	Memory required to execute attack	Number of operations to perform attack
AES	4	TD	2^9	Small	2^9
10 (128)	5	TD	2^11	Small	2^40
12 (192)	6	TD	2^32	7 * 2^32	2^72
14 (256)	6	TD	6 * 2^32	7 * 2^32	2^44
	7 (192)	TD	2^32	7 * 2^32	2^184
	7 (256)	TD	2^32	7 * 2^32	2^200
	8 (256)	TD	2^128–2^119	2^101	2^204
	9 (256)	RK	2^77	NA	2^224
RC6	12	SD	2^94	2^42	2^119
20	14 (192, 256)	SD	2^110	2^42	2^135
	14 (192, 256)	SD	2^108	2^74	2^160
	15 (256)	SD	2^119	2^138	2^215
TwoFish	6 (256)	ID	NA	NA	2^256
16	6	RK	NA	NA	NA

The RC6 cipher's security. The RC6 cipher's intellectual property belongs to the RSA Security [27]. Based on [26], the authors of the RC6 cipher pointed out that due to their original estimate as many as 16 out of the 20 rounds may be vulnerable to attack. As a result, the RC6 provides a very high level of data security: it required 2^215 operations to mount an attack on 15 (with key size = 256) rounds (Table 3.2).

The TwoFish cipher's security. The TwoFish team has mounted an attack on 6 out of the 16 rounds of the TwoFish cipher that requires encryption operations under related unknown keys. Another attack proposed on 6 rounds for the 256-bit key size is no more efficient than exhaustive key search. As a result, the TwoFish cipher appears to offer the highest level of data security: it required 2^256 operations to mount an attack on 6 (with key size = 256) rounds (Table 3.2). However, there is no information on required text size and memory for that attack.

The DES cipher's security. The DES is known as vulnerable [26]; as a result, it should not be used in the MVPN, if the user requires high or medium levels of security of transferred RMM data.

The proposed definitions and mathematical notation of major block ciphers (AES, TwoFish, RC6, DES, 3DES, Camellia, CAST, etc.) and modes (CBC, CTR, GCM, EAX, etc.) enabled us to make the following conclusions based on "theoretical" benchmarking of selected ciphers and modes:

- In terms of data security the AES, the TwoFish, and the RC6 ciphers look very promising for active utilization in the MVPN environment for the WBRMM systems; a note: RC6 cipher is a proprietary one [27].
- In terms of confidential data protection the popular ECB, CBC, OFB, CTR one-phase modes should provide good level of performance but low level of data security.
- The EAX and the GCM modes as representatives of the newest 2-phase Authenticated Encryption with Associated Data (AEAD) modes provide better confidentiality, integrity and authenticity assurances of the data in a single cryptographic scheme. However, due to additional second phase in security-focused constructs in those algorithms, we expect that performances of the AEAD cryptographic schemes will be lower than on-phase modes.

3.5 Research Environment and Research Outcomes

The goal of the developed real-world MVPN environment was to provide adequate to real-world technical environments and quality testing of developed software solutions for various ciphers and modes on various affordable and commonly used mobile technical platforms and test RMM data sets (files) of significantly different sizes.

The description of ciphers, modes, test RMM data sets and technical platforms is situated in Sect. 3.5.1. Section 3.5.2 provides research project outcomes.

3.5.1 Ciphers, Modes, Test RMM Data Sets and Technical Platforms Used

Ciphers and modes analyzed. A set of encryption algorithms (or ciphers) $\{AC\}$ may contain a huge number of various ciphers that can be used for an encryption of data to be transferred through the MVPN tunnel. In order to narrow a subset of ciphers to be benchmarked, the most recent description of the IKEv2 protocol [19] has been used. It reserves the IDs for encryption algorithms, which most likely will be used in IPsec-based MVPNs in the near future. As a result, one of the objectives of this research project was performance benchmarking of the following block ciphers: AES, RC6, RC5, TwoFish, CAST, Camellia, IDEA, DES, and DES/3DES (or, Triple DES).

Table 3.3 Test RMM data sets used

RMM data set's name (MB)	Exact size of test RMM data set (in Bytes)
5	5,799,936
10	52,126,418
100	104,252,836
150	156,379,254
200	208,505,672
250	260,632,090
1,000	1,042,528,360

The currently popular cipher modes such as ECB, CBC, OFB, CFB, CTR and XTS [24, 28, 29] provide various levels of only one characteristic—data confidentiality. However, due to available reports on mode's security, for example [30], these modes of cipher operation are not reliable in terms of confidential data protection against accidental modification or malicious tampering.

The newest 4th generation of cipher modes—the AEAD modes [31, 32] provides confidentiality, integrity, and authenticity assurances on the data in a single cryptographic scheme. The EAX [32, 33] and the Galois/Counter Mode (GCM) [25, 34] are among the most promising AEAD modes.

The other objective of this research project was performance benchmarking of the following cipher modes: the CBC, the CTR, the GCM and the EAX.

Test RMM data sets used. The names of test RMM data sets used in this research project and their exact sizes in Bytes are given in Table 3.3; details on the RMM test data files' characteristics are available in [1, 25, 33, 35].

Mobile technical platforms used. A summary of various affordable and commonly used mobile technical platforms used in this research project is presented in Table 3.4; details on technical platforms used are available in [1, 25, 33, 35].

All analyzed encryption algorithms were coded in C++ and compiled with Microsoft Visual C++ 2005 SP1 (with whole program optimization and optimization for speed).

Legend used. The following legend is used to reflect obtained research outcomes in Tables 3.5, 3.6, 3.7 and Figs. 3.6, 3.7, 3.8:

- Test RMM data set: a name of test RMM data set based on size of the RMM ready-to-be-streamed files to be encrypted (5, 50, 100 and 150 MB, etc.).
- *TIME*: a time (in seconds) needed to encrypt the entire test RMM data set.
- *PERF*: a performance of a particular cipher in MB/s, where 1 MB = 1,000,000 Bytes/s.
- *CYCLES*: number of clock cycles needed to encrypt one byte of data (in 1/Byte).
- *MEDIAN*: median values of corresponding calculated parameters.

Table 3.4 Mobile technical platforms used

Technical platforms used	Specs of technical platform used	Operating system used	CPU mode used
Technical platform 1 (TP1)—a powerful mobile laptop (of "desktop replacement" type): Dell Latitude Core i5	Intel Dual Core i5-2,520 M, 2.50 GHz, 1,066 MHz, Intel 6300 Wireless-N, Intel HD Graphics 3000, 320 GB Hard Drive, 4 GB DDR3 ECC SDRAM 1,333 MHz (2 DIMMs)	Genuine Windows 7 Professional 64-bit	• 1Proc
			• MProc
		Linux 2.6.39	• 1Proc
			• MProc
Technical platform 2 (TP2)—a simulation of commonly used netbook (of "thin and light, for everyday mobile computing" type): Asus Seashell 1005PE	1.66 GHz Intel N450 Atom Processor, 1 GB DDR2 RAM, 2 GB, 250 GB SATA Hard Drive (5400RPM), 802.11 b/g/n	Windows 7 Starter operating system	• 1Proc
			• MProc
		Linux 2.6.39	• 1Proc
			• MProc
Technical platform 3 (TP3)—used in the current (as of Dec 2013) version of the CRYPTO++ 5.6.0 library	Intel Core 2 1.83 GHz processor	Windows Vista in 32-bit mode	• 1Proc
		Linux	• 1Proc

3.5.2 *Research Project Outcomes*

A full pool of research project's outcomes include data for all possible combinations of above-mentioned block ciphers, modes of cipher operations, mobile technical platforms, modes of CPU operation, and operating systems. Due to the space limit in this chapter, a selected set of project outcomes is presented below.

Tables 3.5, 3.6 and 3.7 contain summaries of ciphers' performance with median values of calculated parameters *PERF* and *CYCLES* for all RMM test data sets. Table 3.5 contains data for ciphers in 1-phase CBC mode [4], Table 3.6—in 1-phase CTR mode [35], and Table 3.7—in 2-phase GCM mode [25]; those data were obtained from tests using technical platforms TP1 and TP2 with Windows operating systems (OS) in both single processor *1Proc* and multi processor *MProc* modes of CPU operation.

Column # 7 in Tables 3.5, 3.6 and 3.7 represents the only available data for those modes in the Crypto++ library [36]. (A note: the Crypto++ library uses MiB (Mebibyte) unit to measure cipher performance, where 1 MiB = 2^20 = 1,048, 576 bytes; as a result, a correction factor of 1.0485 has been used for Crypto++ data to present it in column # 7 in Tables 3.5, 3.6 and 3.7).

Table 3.5 Ciphers' performance in the CBC mode—only median values for *PERF* and *CYCLES*

Cipher–mode	Calculated parameter	TP1 (powerful Dell laptop with Windows OS)		TP2 (generic Asus netbook with Windows OS)		TP3 (with Windows OS) [36]
		1Proc	*MProc*	*1Proc*	*MProc*	*1Proc*
1	2	3	4	5	6	7
AES-CBC	*PERF*	163.011	163.174	22.772	22.705	114.2
	CYCLES	14.602	14.632	69.533	69.733	15.2
RC6-CBC	*PERF*	114.511	114.483	29.681	28.343	
	CYCLES	20.828	20.834	54.110	59.472	
RC5-CBC	*PERF*	113.165	112.601	31.683	33.498	
	CYCLES	21.074	21.182	51.462	47.274	
TwoFish-CBC	*PERF*	85.497	85.165	21.069	20.927	
	CYCLES	27.896	28.005	75.172	75.652	
CAST-CBC	*PERF*	70.471	70.467	20.922	21.222	
	CYCLES	33.833	33.835	75.669	74.618	
Camellia-CBC	*PERF*	68.147	68.146	18.969	18.918	
	CYCLES	34.995	34.995	83.475	83.685	
IDEA-CBC	*PERF*	54.996	54.914	15.304	15.447	
	CYCLES	43.386	43.452	103.455	102.484	
DES-CBC	*PERF*	44.832	44.782	10.858	10.966	
	CYCLES	53.182	53.241	145.810	144.363	
3DES-CBC	*PERF*	18.365	18.348	4.353	4.389	
	CYCLES	129.821	129.941	363.722	360.731	

A summary of ciphers' performance in 1-phase CBC mode on mobile technical platforms TP1 and TP2 for RMM test data sets—only median values of parameters *PERF* and *CYCLES*

Data on Figs. 3.6 and 3.7 represent obtained ciphers' performance—only calculated parameter *PERF* (in MB/s)—for each RMM test data set (5, 50, 100, 150 and 200 MB, etc.); obtained data correspond to technical platform TP1 (with Windows OS and CPU in single processor *1Proc* mode) in CBC mode (Fig. 3.6) [4] and CTR mode (Fig. 3.7) [35].

Data on Fig. 3.8 represent AES-128 cipher performance—only calculated parameter *PERF* (in MB/s)—for each RMM test data set (5, 50, 100, 150 and 200 MB, etc.); obtained data correspond to technical platform TP1 (with Windows and Linux OS, and CPU in single processor *1Proc* mode) in the CBC [4], the CTR [35], the EAX [33], and the GCM [25] modes.

A summary of AES-128 cipher performance outcomes (Fig. 3.8) is as follows:

- AES-128 in the CTR mode has the highest performance on TP1 with Windows OS (on average—about 215 MB/s) and on TP1 with Linux OS (about 180 MB/s); the AES-128 on TP1 with Windows OS is the absolute champion among all ciphers and modes in terms of performance.

Table 3.6 Ciphers' performance in the CTR mode—only median values for *PERF* and *CYCLES*

Cipher–mode	Calculated parameter	TP1 (powerful Dell laptop with Windows OS)		TP2 (generic Asus netbook with Windows OS)		TP3 (with Windows OS) [36]
		1Proc	*MProc*	*1Proc*	*MProc*	*1Proc*
1	2	3	4	5	6	7
AES-CTR	*PERF*	208.0	209.0	28.1	28.3	145.1
	CYCLES	11.9	11.9	59.0	58.5	12.0
RC6-CTR	*PERF*	126.3	126.3	33.4	32.6	106
	CYCLES	19.7	19.7	51.8	51.6	16.5
RC5-CTR	*PERF*	124.1	124.2	37.6	38.9	78.6
	CYCLES	20.1	20.1	46.1	43.0	22.3
TwoFish-CTR	*PERF*	91.4	92.0	22.7	23.1	61.8
	CYCLES	27.3	27.1	73.0	71.8	28.0
CAST-CTR	*PERF*	74.1	74.1	23.5	24.0	57.6
	CYCLES	33.7	33.6	70.4	69.1	30.4
Camellia-CTR	*PERF*	73.1	73.1	20.6	21.0	50.3
	CYCLES	34.1	34.1	80.3	78.8	34.6
IDEA-CTR	*PERF*	59.7	59.7	16.7	16.9	36.7
	CYCLES	41.8	41.8	99.0	98.0	47.6
DES-CTR	*PERF*	47.0	47.1	12.2	12.4	33.5
	CYCLES	53.1	53.0	135.1	133.1	52.1
3DES-CTR	*PERF*	19.2	19.2	4.6	4.7	13.6
	CYCLES	129.1	129.1	358.0	353.0	127.1

A summary of ciphers' performance in 1-phase CTR on mobile technical platforms TP1 and TP2 for the RMM test data sets—only median values of parameters *PERF* and *CYCLES*

- AES-128 in 2-phase GCM and 1-phase CBC modes has approximately the same performance on TP1 with Windows OS (about 170 MB/s).
- AES-128 in 2-phase EAX mode has the lowest performance on TP1 with both Windows OS (about 100 MB/s) and Linux OS (about 80 MB/s) among all tested modes.
- In each particular tested mode, the AES-128 on TP1 with Windows OS has about 15–25 % higher performance than on TP1 with Linux OS.

Table 3.7 Ciphers' performance in the GCM mode—only median values for *PERF* and *CYCLES*

Cipher–mode	Calculated parameter	TP1 (powerful Dell laptop with Windows OS)		TP2 (generic Asus netbook with Windows OS)		TP3 (with Windows OS) [36]
		Mode of CPU operation		*Mode of CPU operation*		
		1Proc	*MProc*	*1Proc*	*MProc*	*1Proc*
1	2	3	4	5	6	7
AES-GCM	*PERF*	173.01	170.76	17.38	17.44	113.24
	CYCLES	14.47	14.69	244.11	301.99	16.10
RC6-GCM	*PERF*	112.31	112.49	19.46	19.30	
	CYCLES	22.29	22.25	233.12	348.83	
TwoFish-GCM	*PERF*	84.50	84.78	5.99	15.27	
	CYCLES	29.62	29.52	617.60	257.04	
Camellia-GCM	*PERF*	68.52	68.67	14.07	9.12	
	CYCLES	36.52	36.44	266.91	381.64	

A summary of ciphers' performance in 2-phase GCM mode on mobile technical platforms TP1 and TP2 for the RMM test data sets—only median values of parameters *PERF* and *CYCLES*

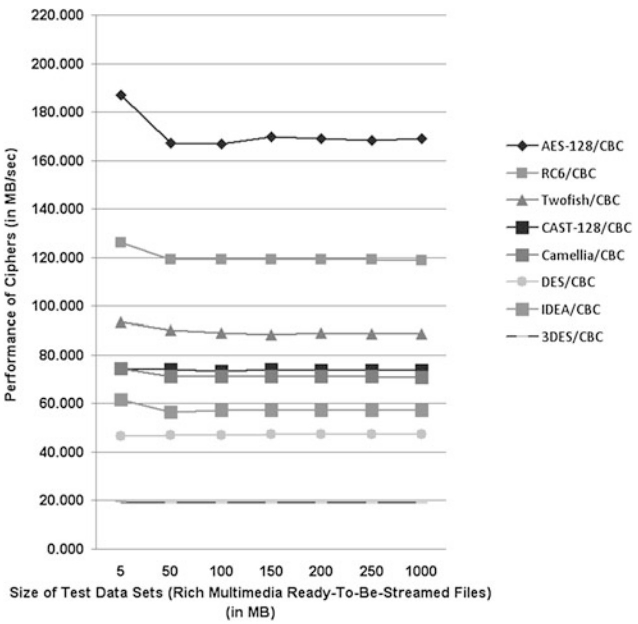

Fig. 3.6 Ciphers performance in the CBC mode—cipher performance for each RMM test data set (a summary of ciphers' performance in the CBC mode for each RMM test data set on technical platform TP1 with Windows OS and CPU in *1Proc* mode)

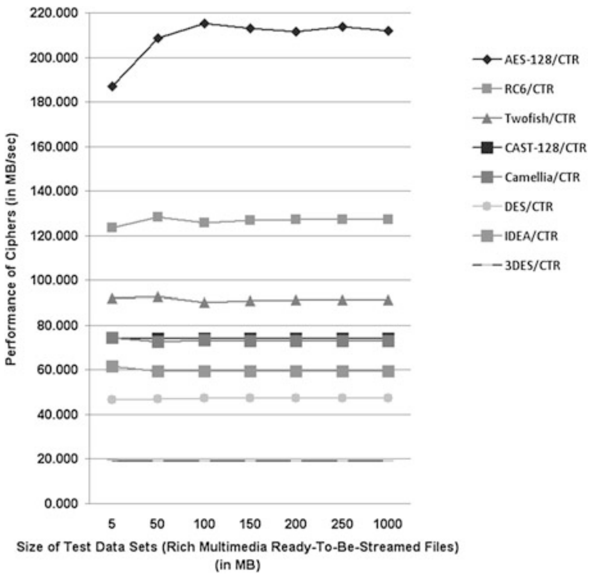

Fig. 3.7 Ciphers performance in the CTR mode—cipher performance for each RMM test data set (a summary of ciphers' performance in the CTR mode for each RMM test data set on technical platform TP1 with Windows OS and CPU in *1Proc* mode)

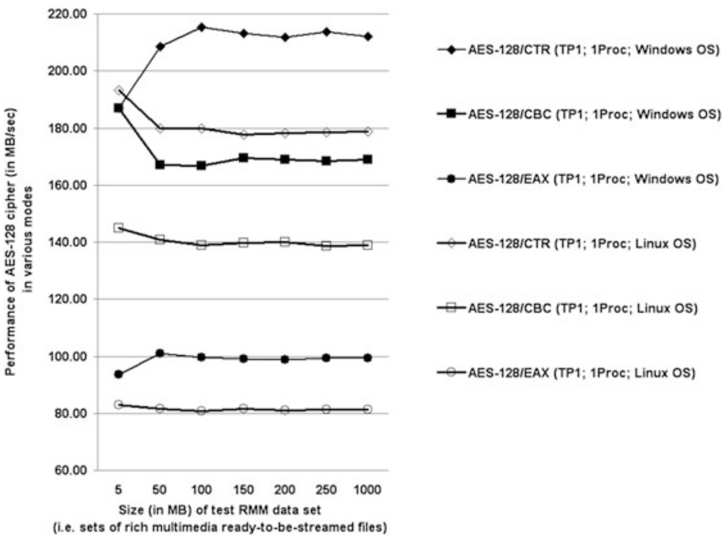

Fig. 3.8 AES-128 cipher's performance in the CBC, the CTR, the GCM, and the EAX modes for each RMM test data set (a summary of AES cipher performance—values of calculated parameter *PERF*—for each RMM test data set on technical platform TP1 with Windows and Linux OS, and CPU in *1Proc* mode)

3.6 Conclusions and Recommendations. Next Steps

Conclusions and recommendations. The theoretical findings and outcomes of this research, design and development project, multiple obtained numeric data, numerous designed and developed IPsec MVPN solutions, their practical implementation and active use in actually working WBRMM systems enable us to make the following conclusions:

- A fusion of software and network security, mobile computing and rich multimedia technologies is an emerging tendency these days. One of the most important technical implementations of such a fusion is mobile Web-based rich multimedia systems that are in high demand today by numerous mobile users with significantly different levels of requirements to security, performance, and total cost of the MVPNs.
- The proposed and developed CM-MVPN, IS-MVPN, and especially DM-MVPN models are important for mobile network managers and system administrators on terms of better understanding and development of effective (in terms of security, performance and total cost) MVPNs and WBRMM systems for mobile users.
- A highly secure VPN technology is a powerful modern information security technology for corporate wide area networks. However, due to the MVPN complexity and numerous possible choices and options, a particular MVPN solution should be created in accordance with the proposed design methodology DM-MVPN by well-trained and experienced MVPN or network manager or system administrator.
- The proposed MVPN conceptual models and design methodology, multiple practical IPsec-based MVPN design solutions have been tested, implemented and used by various users (faculty, content developers, research associates) in authors' university from 2009. No significant information security breaches had been identified in developed MVPNs since that time despite the fact that more than 900 unique computer attacks on streaming/data/Web servers of the developed MVPN have been registered by security systems in April 2014 alone.
- The popular 1-phase ECB, CBC, OFB, CTR modes of cipher operation provide low level of data security and are not reliable in terms of confidential data protection. As a result, in general, we do not recommend those ciphers to be used in the MVPN for confidential data transfer. On the other hand, those cipher modes could be recommended for use in the MVPN with "low security + low cost + average performance" user requirements to confidential RMM data transfer in the MVPN.
- The recent 2-phase Authenticated Encryption with Associated Data (AEAD) modes such as the EAX and the GCM provide better confidentiality, integrity, and authenticity assurances of the data in a single cryptographic scheme. However, due to additional security-focused constructs in those algorithms the performance of the AEAD cryptographic schemes is expected, in general, to be lower than of 1-phase modes. As a result, in general, those cipher modes are

recommended for use in the MVPN with "highest level of security + medium cost + medium performance" user requirements to the RMM data transfer in the MVPN.

- The AES cipher demonstrated either the best or one of the best performances for all test RMM data sets on all testing technical platforms and in all modes. It has one of the proven highest levels of security and it is free of charge. As a result, we strongly recommend the AES cipher for active use in IPsec-based MVPNs for WBRMM systems.
- The AES-128 cipher in the CTR mode has the highest performance on TP1 with Windows OS (on average—about 215 MB/s) and on TP1 with Linux OS (about 180 MB/s); the AES-128 on TP1 with Windows OS is the absolute champion among all ciphers and modes in terms of performance on tested technical platforms. Moreover, the CTR mode is fully parallelizable, making it much more attractive for IPsec MVPN administrators and users of WBRMM systems in light of possible use of Graphics Processing Units (GPU) computing for effective encryption/decryption processes.
- One of the surprising outcomes is that the AES-128 cipher in 2-phase GCM and 1-phase CBC modes demonstrated approximately the same performance on technical platform TP1 with Windows OS (about 170 MB/s) and with Linux OS (about 140–155 MB/s); it means that the 2-phase GCM mode with higher than CBC mode security (in terms of additional data authentication and confidentiality) has a competitive performance as well. Moreover, the GCM is fully parallelizable and can be used in GPU computing.
- In each particular tested mode including the CBC, the CTR, the GCM and the EAX, the AES-128 on TP1 with Windows OS demonstrated about 15–25 % higher performance than on TP1 with Linux OS.
- The RC6 cipher in several cases demonstrated the best performance on technical platform TP2 (general-purpose Asus netbook); however, both RC5 and RC6 ciphers are proprietary encryption algorithms that are patented by the RSA Security [27].
- The TwoFish cipher theoretically provides the best levels of data security; however, due to corresponding complexity of this cryptographic schema it proved to be about 2 times slower than the AES and RC6 ciphers in various modes.

Next steps. The next planned steps in this research project are aimed to make a "smarter" fusion of highly secure software and network IPsec-based security technology, mobile computing and rich multimedia technology. In other word, we plan to add smart technology to a combination of security, mobile and multimedia technologies as already required or will be required in the foreseeing future by multiple applications of Web-based and streaming rich multimedia systems. Particularly, we plan to make the developed DM-MVPN design methodology (Table 3.1) "smarter" in terms of "smart" selection of various solutions during design and optimization procedures in the DM-MVPN model. Theoretically, it can be done by incorporation of "smart" characteristics into the DM-MVPN model, including:

- Adapting, i.e. ability to modify physical—at least, software, but ideally, both software and hardware—characteristics of IPsec-based MVPN to better fit and/or serve the mobile environment and mobile users.
- Sensing, i.e. ability to identify potential and actual problems/conflicts during the MVPN design, development, implementation and maintenance processes.
- Inferring, i.e. ability to automatically make logical conclusions based on obtained network raw data, information, rules, types of users with various requirements to IPSec-based MVPN's security and performance etc.
- Self-training/learning, i.e. ability to acquire/generate new knowledge or modify the existing one to improve (in ideal case, optimize) IPsec-based MVPN overall effectiveness (i.e. the security-performance-cost ratio).
- Anticipation, i.e. ability of reasoning to predict IPsec-based MVPN's status, operation, performance and security in various abnormal cases.

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Chapter 4
Teaching and Promoting Smart Internet of Things Solutions Using the Serious-Game Approach

Enn Õunapuu

Abstract In the era of technological advances, the rapid development of network connected objects, cloud computing, software development methodologies, and teaching techniques direct us to the smart solutions. The objective of the chapter is to propose a methodology for teaching and promoting smart internet of things solutions based on the serious-game approach. In the serious-games approach, the simulations of real-world events or processes are used to analyze complex situations and propose solutions. The usage of serious games is entertaining, but their primary goal is to train and educate people; simultaneously, this approach may have other purposes such as marketing or advertisement.

Keywords Internet of things · Serious games · Bio-inspired computing · Model driven engineering · Decision theory · Smart solutions

4.1 Introduction

Nowadays, dynamic world requires changes in our ways of teaching. Traditional teaching methods, in which the non-interactive lectures are the main form of teaching, does not give the desired result. Our challenge now is to increase a student participation and interest. One promising direction in the search for the solution is the use of serious games in teaching.

In this chapter, a methodology for augmented teaching and promoting smart internet of things solutions is developed. The distinctive feature of our approach is that the simulated situation is notably close to the real situation. For example, for the smart house solutions, the model of the house is used. Simultaneously, all sensors, building automation equipment, and software are real. The other important

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feature of our approach is the model-driven internet of things development method. The goal model, decision model, process model, data model, user interface model, and integration model define the solution, and the user can strictly begin to test the application. All solutions are usable on mobile devices.

The introductory paragraph defines the basic concepts that are used in this chapter and presents an overview of the related works. Thereafter, the model-driven approach to the internet of things is presented. The main distinctive features of the methodology are the usage of a decision model in conjunction with a process model. These models are described in the following paragraphs of this chapter. The background and related work are discussed in Sect. 4.2. After the methodology description in Sect. 4.3, an example of the usage of the proposed methodology to teach the smart house solutions is presented in Sect. 4.4. Finally, the results and future research directions are drawn in Sect. 4.5.

4.2 Background

The main augmented learning authority is Klopfer. In his book [1], Klopfer describes the largely untapped potential of mobile learning games, which are played on handheld devices, such as smart phones, to make a substantial impact on learning. Examining mobile games from both educational and gaming perspectives, Klopfer argues that the strengths of the mobile platform, which are its portability, context sensitivity, connectivity, and ubiquity, make it ideal for learning games in elementary, secondary, university, and lifelong education.

These games, which are either participatory (require an interaction with other players) or augmented reality (augment the real world with virtual information), can be produced at lower cost than PC or full-size console games. They use social dynamics and real-world contexts to enhance the game play, can be integrated into the natural flow of instruction more easily than their big-screen counterparts, and can create compelling educational and engaging environments for learners [1].

The internet of things [2, 3] refers to uniquely identifiable objects and their virtual representations in computer networks. The term “internet of things” was proposed by Ashton in 1999. The concept of the internet of things first became popular through the Radio-Frequency IDentification (RFID). If all objects and people in daily life were equipped with identifiers, they could be managed and inventoried by computers. In addition to using RFID, the tagging of things may be achieved through technologies such as Network Control Facility (NCF), barcodes, QR codes, and digital watermarking.

The Model-Driven Engineering (MDE) [4] is a software development methodology that focuses on creating and exploiting abstract representations of the knowledge and activities that govern a particular application domain instead of on the computing (or algorithmic) concepts. A decision theory [5] is concerned with identifying the values, uncertainties and other relevant issues in a given decision with its rationality and the resulting optimal decision. Our goal is to create a solution (tool) and maintain a serious game to teach the course "internet of things smart solutions".

The aforementioned tool should possess the following qualities:

- The game situation must be as close to the real situation as possible.
- In the game, it is possible to address uncovered solutions—innovation orientation.
- The solution that is proposed by the students must be tested and supported by the analytical tools using open data.
- The system and the student solutions are created using the Model-Driven approach.
- The system and the student solutions must adapt to the changes in environment, which is a self-organization feature.
- The system must work on smart phones.
- The open use of sensors and actuators including those in the development stage.

This section involves the following issues. Section 4.2.1 provides basic concepts; literature review is situated in Sect. 4.2.2. Project goal and objectives are pointed in Sect. 4.2.3. Section 4.2.4 includes innovative approaches in education framework.

4.2.1 Basic Concepts

Serious game. Michael and Chen provide the following definition [6]: "A serious game is a game in which education (in its various forms) is the primary goal, rather than entertainment". Some areas, where serious games are actively used, are aviation, automotive industry; however, in education, their use is unsustainably low-level possibly because of the high price and their respective methodological material shortage. In this chapter, we attempt to reduce these weaknesses.

Internet of things. Among many definitions of internet of things, the definition of Stephen Haller can be regarded as the best definition: "A world where physical objects are seamlessly integrated into the information network, and where the physical objects can become active participants in business processes. Services are available for interacting with these 'smart objects' over the internet, query and change their state, and any information associated with them, took into account security and privacy issues" [2].

This definition includes all the important features of this approach:

- Physical objects are integrated to the network over the internet.
- These objects are active participants in business processes.
- In the usage of these objects, the privacy and security issues are highly valued.

These features are also under deep attention in this chapter. Let us define the Internet of Things (IoT) domain model, which is developed by extending excellent models that are found in the literature [7, 8]. Unfortunately, there is no clear definition in the IoT modeling; however, those definitions could be crucial for making solutions.

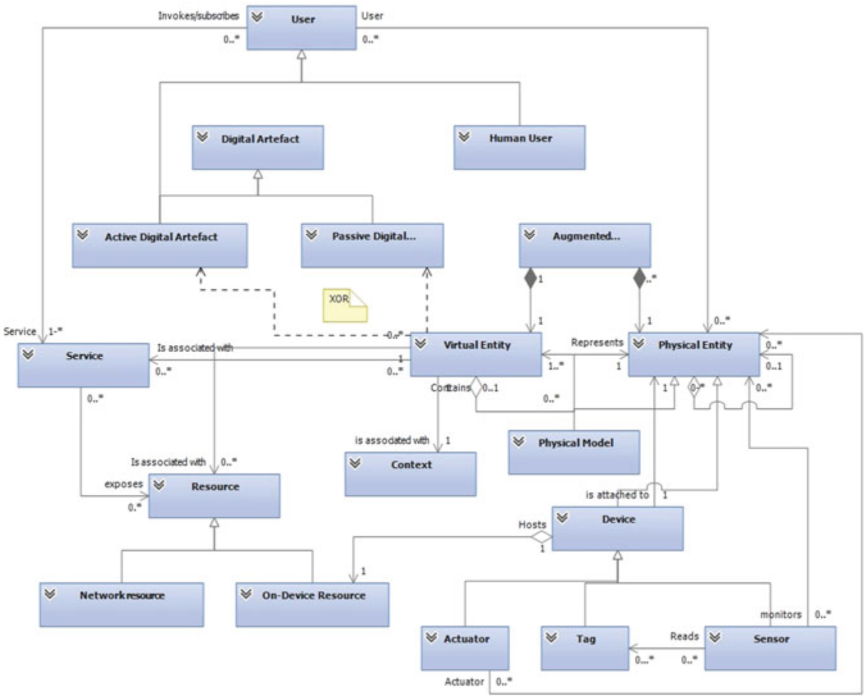

Fig. 4.1 The IoT domain model [7]

The Concepts of the IoT Domain Model. According to the IoT definition, the central notion is Physical Entity (PE) in the real world (see Fig. 4.1), which is seamlessly integrated into information networks. The PE also has a self-referential relationship, which is a notably powerful relationship that enables the entity to reflect on the hierarchies of physical things. For example, in the city, we have houses, which have many grounds, each of which has many flats. The top hierarchy of the object constitutes the context of the lower hierarchy of the object. In the domain model, two other key entities of the IoT are introduced: *Human User* and *Digital Artefact* (service, software agent, application) that interacts with the PE.

Physical Objects are represented in IT by *Virtual Entities*. There are different types of digital representations of *Physical Objects*:

- Database entries.
- Object (instance of the class).
- 3D models.

Virtual Entities are *Digital Artefacts,* which can be of two types:

- *Active Digital Artefact* (software applications as software agent or *Services).*
- *Passive Digital Artefact* such as database entry.

There is a significant difference between a Physical Entity (PE) and a Virtual Entity (VE). The VE belongs to a virtual world, and the PE belongs to the real world. However, in our approach, they should be synchronized. To achieve this synchronization, the Information and Communications Technology (ICT) device is used, which provides the interface to interact with or gain information about the PEs [9]. Thus, we use *sensors*, *tags*, and *actuators*.

Context and context-awareness. The IoT will allow one to do a lot more than considering the situational context. Sensors, Open Data, and Big Data provide a completely new face to our solutions. There are many definitions of contexts. The definition that best satisfies our requirements is: "*Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves*" [10].

Abowd and Day [10] also introduced the primary context types:

- Location—location data from the GPS sensor.
- Identity—Identify object based on the RFID tag.
- Time—read time from clock, also daytime.
- Activity—What activities are in progress?

There is also a secondary context type, which is derivative information that we can use based on the primary context. For example, using Identity, we can obtain considerable information about a person in social networks and the internet.

In our case, the context information is the place, where we can begin to play. Our system can introduce a new situation and sets new context information and state information. Based on the response of the student reactions, we make changes in the state. Thereafter, we evaluate the adequacy of the student responses.

Adaptation and self-organization. For our approach, the adaptive and self-organizing properties are exceptionally valuable. Instead of attempting to find the most optimal solution based on the available information, we attempt to use self-organization methods. For example, it is known that city public transportation planning is a highly complex and difficult problem. The situation can change notably quickly, and our perfect plan fails. Instead of careful planning, we attempt to use adaptive techniques. For example, we can obtain information about transport needs from the sensors and quickly send our reserve buses to the necessary place.

The most general self-organizing definition is provided in [11]: *"Self-organization is a process in which pattern at the global level of a system emerges solely from numerous interactions among the lower-level components of the system. Moreover, the rules specifying interactions among the system's components are executed using only local information, without reference to the global pattern*".

The complexity of systems is accompanied by an increase in the importance of self-organizing systems increases.

Smart solutions. The smart-solution concept is notably important in the context of this chapter. The creation of smart solutions is exactly, what we want our students to teach. Of course, we want to make it as smartly as possible.

Smart refers to quick intelligence. People are considered smart, when he/she shows the rapid ability to respond intelligently to different situations. As we observe, smartness is strongly connected with the concept of intelligence [12, 13]. It is a long debate regarding, whether we can exhibit the intelligence to computers or software. Today's computers can do many things that require intelligence such as driving a car in city.

The term “intelligent systems” is used to describe the necessary level of capabilities to achieve the system goals. Intelligence has been scientifically categorized as a biological stimuli response mechanism. In our case, we obtain the stimulus from the environment using different sensors and make a response using the knowledge that we have and the actuators that are connected to the system. During its lifecycle, the system learns from experience. The learning ability is precisely that makes the system intelligent. Computer power and the amount of information and sensors make a system smart.

Smart solutions are composed of smart objects [14]: “One definition of smart objects is a purely technical definition—a smart object is an item equipped with a form of sensor or actuator, a tiny microprocessor, a communication device, and a power source. The sensor or actuator gives the smart object the ability to interact with the physical world. The microprocessor enables the smart object to transform the data captured from the sensors, albeit at a limited speed and at limited complexity. The communication device enables the smart object to communicate its sensor readings to the outside world and receive input from other smart objects. The power source provides the electrical energy for the smart object to do its work.” These objects can learn and adapt to different real-world situations, and different machine learning algorithms are used [15].

Let us define smart solutions to a problem as a solution that integrates computer and networking power and uses smart objects as tools to make decisions in a manner that exceeds the possibilities of the traditional solutions. For example, Smart City solutions are more effective than the traditional ones, Smart House solutions are more energy-efficient, secure, and comfortable than traditional houses, etc. Therefore, evolution criteria for smart solutions cover the efficiency, security and performance indicators of the solution.

4.2.2 Literature Review

This subsection discusses two domains: the internet of things and the serious-games approach to teaching. The serious-game approach to teaching is one of the most promising methods to select a new direction in education. With the development of digital information technology, the usage of digital games is increasing. According to [16], 11- to 14-year olds play video games for 90 min per day, which has been viewed as a major contemporary problem. However, a number of authors also refer to the positive effects of playing games. Video games force children to think quickly and make decision in different situations. Thus, we are faced with a large challenge to direct a person of interest to the useful tool for acquiring new knowledge and skills. Serious games are designed for these reasons [17–19]. To align learning and fun, there are several possibilities:

- One can create unique software with attractive interface and narratives.
- One can use existing specialized software and create gaming illusion using special situation stories (narratives) and environment variable settings.

In this chapter, the second approach is used, where learners do not feel that the learning part is something external to the game. Multimodality and interactivity [20] are the basic features that allow to drive the learning process. Multimodality is a property of games that allows the presentation of content knowledge in different forms: visual, auditory, and other sensory modalities. Interactivity allows different forms of activities for interacting with the gaming environment. The learner can influence the trajectory of the game.

A huge amount of scientific literature is published on the internet of things, and it does not make sense to address the entire matter because there are corresponding surveys [21]. This chapter focuses on the information that we obtain from the sensors and sages to the decisions that we make as a result. The internet of things for smart environments is defined as [22]: "Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless ubiquitous sensing, data analytics and information representation with Cloud computing as the unifying framework".

To create the smart internet of things solutions, the main focus should be given to data storage and analytics. For real-time processing and storing data, the noSQL databases are used [23]. Data analytics includes artificial intelligence algorithms for temporal machine-learning and decision-making processes [24]. There are extensive studies on internet of things and serious games separately, and these topics are notably relevant today. However, there are few studies that address these topics together.

Nevertheless, notably thorough job has been done in this area in the framework of the EU project ELLIOT [25]. As read in the project's website: "The ELLIOT (Experiential Living Lab for the internet of things) project aims to develop an internet of things (IoT) experiential platform, where users/citizens are directly involved in co-creating, exploring and experimenting new ideas, concepts, and technological artifacts related to IoT applications and services."

Serious games are notably important in the ELLIOT project. Although the gaming approach is mainly used in the co-creative phase to develop suitable IoT services, the use of a serious game is not limited to this phase but is also used in the development and support phase. The ideas that are developed in the game are passed on to the ELLIOT team members for further discussion, development, and feedback collection. In other words, in the project ELLIOT, the serious game approach is mainly used for requirement engineering of a new solution. The requirement engineering is the process to elicit, analyze, validate, and document a formal, complete and agreed requirements specification. The ELLIOT approach is an oriented innovation, where innovative thinking is guided by the Synectics method [26] and supported with predefined scenarios. Game playing and role playing offer two important directions to acquire requirements with a particular focus on the interactions during group work and to the simulated environments.

4.2.3 Project Goal and Objectives

The goal of the project is to develop a methodology and experimental platform for teaching and promoting smart internet of things solutions. For this purpose, the serious-game approach is used. In the serious-games approach, the simulations of real-world events or processes are applied to analyze complex situations and propose solutions. The serious games are entertaining to use, but their main goal is to train and educate people; simultaneously, it may have other purposes such as marketing or advertisement. The experimental platform is the place where the users/ students can directly create and explore new ideas, concepts, and technological artifacts that are related to the IoT applications and services.

To achieve a goal, the following objectives are set:

- Study and develop the MDE methodology to create innovative IoT solutions, where a solution is fully defined using different models (goal or motivation model, business process model, database model, integration model, and security model).
- To facilitate the preparation of a business process model, we develop the business process archetype pattern approach. Our approach can be characterized as process-aware, where the business process model is in a notably important position.
- Design and develop a platform, where the real conditions are simulated setting context parameters.
- Explore the potential serious gaming approach for teaching and promoting smart IoT solutions.
- Experiment with different IoT applications in the smart-home domain, each of which is composed of different physical space approaches, information space architecture and communication protocols. Various scenarios are defined in these sectors and will allow exploring and validating our approach, the experimental platform and the co-creation techniques and tools.

The project should enhance the effectiveness of teaching and increase the adoption of the IoT in society.

4.2.4 Innovative Approaches to Be Used

Nowadays, dynamically changing world continuously presents us with new challenges. The increasing use of information technology in all areas highlights the necessity to change the method that we create these solutions. Although there has been considerable progress in this regard, radical changes are now required in this domain. Currently, information system development is an expensive, time-consuming, and highly qualified activity. In the near future, a new method should be obtained. A model-driven engineering is one of the promising approaches for information system development. In this project, the MDE approach is developed in two directions: the process archetype concept is introduced and adopted, and the usages of goal models are enhanced. The targets of the system are presented in the form of a clear goal model. All activities in the system are aligned with this model.

Second major challenge is related to the education system. Information technology, the internet, and social network development lead us to the situation that we must rethink our teaching methodology. The traditional lecture-based, no feedback teaching should be replaced by a much more interactive and efficient methods, where the students are highly involved. The serious-game approach is notably appropriate in this case. In our project, a serious-game approach is enhanced with model-driven development methods and new methods of creating gaming conditions. Our serious-game software is based on industrial solutions, and we create teaching-situation setting environment variables, which allow us to make the student experience notably close to the real-life experiences, and the knowledge that they obtain is strictly usable in practice. Additionally, the students are involved in the creation of innovative IoT solutions. All of this together creates a new, innovative approach to creating smart internet of things solutions and their teaching.

4.3 Model-Driven Approach

The model-driven approach is how the current Information Technologies (IT) solutions can be realized because the current IT solutions no longer satisfy the modern-time requirements. The creation and modification of the IT solutions today are costly, time-consuming, and mainly manual work. We need new approaches. A promising possibility is to use the MDE approach. One of the central models in this approach is the business process model. The following discussion is highlighted as business process modeling (Sect. 4.3.1) and data and process archetypes (Sect. 4.3.2).

4.3.1 Business Process Modeling

The process: A coherent set of activities that leads to a result (product or service) is conducted by a group of cooperating actors. In particular, the result can be the outcome of the interaction between (the things in) the domain and the things outside the domain.

A process has goals, which can fit the system goals (Fig. 4.2). These goals must have measures. The process begins with is the initial subset of unstable states

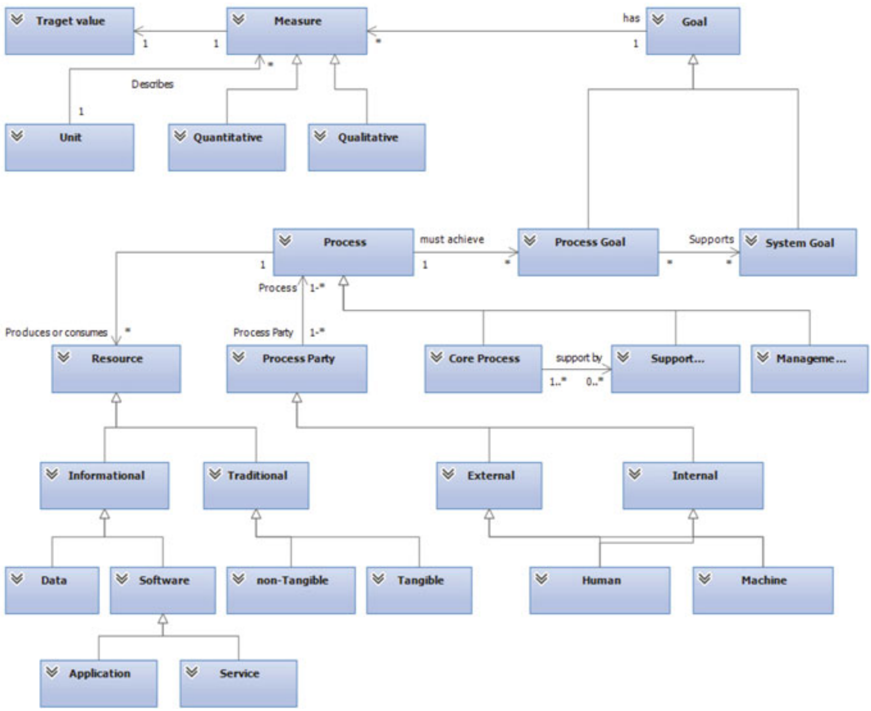

Fig. 4.2 Process conceptual context

(of the domain). Considering that the domain has been in a stable state before the process initiation, these states result from events that are external to the domain, and these events trigger the process. It is important to note that the starting point of the process is an unstable state because the initial unstable state of the domain determines how the process will proceed. This initial state is attained via various combinations of a prior (stable) state and an external event.

For practical reasons, we may not include all state variables of things in the process state. Note that the definition of a process implies that to be a process, a set of ordered activities must lead to a defined goal. Finally, we recognize that the process might progress through different sequences of states, which depends on the initial state and the state changes that are caused by external events of the process domain. The method to see the notion of goal is incorporated into the abstract (state-based) view of the previously described process.

Processes are executed to achieve some predefined outcomes. These results are consistent with some organizational objectives (system goal). We term the desired result of the process as a **process goal**. A process goal is formed using state variables and must have exact measures. It is notably important to have on-place target values for process goals, which allows a self-adaption of the system. Different options for sub processes enable one to make directed decisions.

4.3.2 Data and Process Archetypes

The Merriam-Webster dictionary defines [27]: "Archetype—the original pattern or model of which all things of the same type are representations or copies". In the field of informatics, an archetype is a formal re-usable model of a domain concept. Traditionally, the term archetype is used in psychology to indicate an idealized model of a person, personality, or behavior. The usage of the word in informatics is derived from this traditional meaning but applied to domain modeling instead. An archetype is defined by the OpenEHR foundation [28] for health informatics as follows.

An archetype is a computable expression of a domain content model in the form of structured constraint statements based on some reference model. The OpenEHR archetypes are based on the OpenEHR reference model. All archetypes are expressed in the same formalism. In general, they are defined for wide re-use; however, they can be specialized to include local particularities. They can accommodate any number of natural languages and terminologies.

The use of archetypes in health informatics was first documented by Thomas Beale, who stated that the concept was coined by Derek Renouf. According to [29], archetypes were applied to configure Smalltalk systems. Business archetypes and archetype patterns were originally designed and introduced by Arlow and Neustad [30]. Recently, a defended thesis at the Tallinn University of Technology proposed a refined and enhanced version of business archetypes and archetype patterns. This refined and enhanced version of archetypes and archetype patterns were used to engineer business domains, requirements, and software. The methodology is used for clinical-laboratory domain model in real-life Laboratory Information Systems (LIMS) development [31].

Beyond the state of the art. All referred archetypes are in the class of object-oriented design patterns. Object-oriented design patterns typically show relationships and interactions among classes or objects without specifying the final application classes or involved objects. In our approach, we use archetype principles in the business processes. Our approach is process-aware. Process-Aware Information System (PAIS) can be defined as a software system that manages and executes operational processes that involve people, applications, and/or information sources based on the process models [32].

The most prominent author in this area is van der Aalst. In process-aware information systems, different perspectives can be distinguished. The control-flow perspective captures aspects that are related to control-flow dependencies among different tasks (e.g., parallelism, choice, synchronization, etc.). Originally, 20 patterns were proposed for this view, but in the latest iteration, this number has grown to over forty patterns. The data view addresses the passing of information, scoping of variables, etc., whereas the resource view addresses resource to task allocation, delegation, etc. Finally, the patterns for the exception-handling view address different causes of exceptions and different actions that must be taken as a result of the occurring exceptions [33].

We make one step forward to the business direction. Our process archetypes are an abstract notion of one or more service utilities, which are used in the business process with many models. Domain-specific multi-modeling [34] is a software development paradigm, where each view is made explicit as a separate Domain-Specific Language (DSL). Successful development of a modern enterprise system requires the convergence of different views. Business analysts, domain experts, interaction designers, database experts, and developers with different types of expertise all participate in the process of building such a system. Their different work products must be managed, aligned, and integrated to produce a running system. Every participant of the development process has a particular language that is tailored to solve problems that are specific to its view on the system. The challenge of integrating these different views and avoiding the potential cacophony of several different languages is the coordination problem [34].

In our approach, the business process archetype model, which is central, is supported by additional domain-specific models such as:

- Motivation Model: measures the business process efficiency.
- Decision Model: is used by both service providers and business people to define the international, national, organizational, and other business rules for a particular service.
- End User Interface Model: defines the needed interfaces for the end-user (e.g., what the end user must input or choose as information and what the necessary service output is).

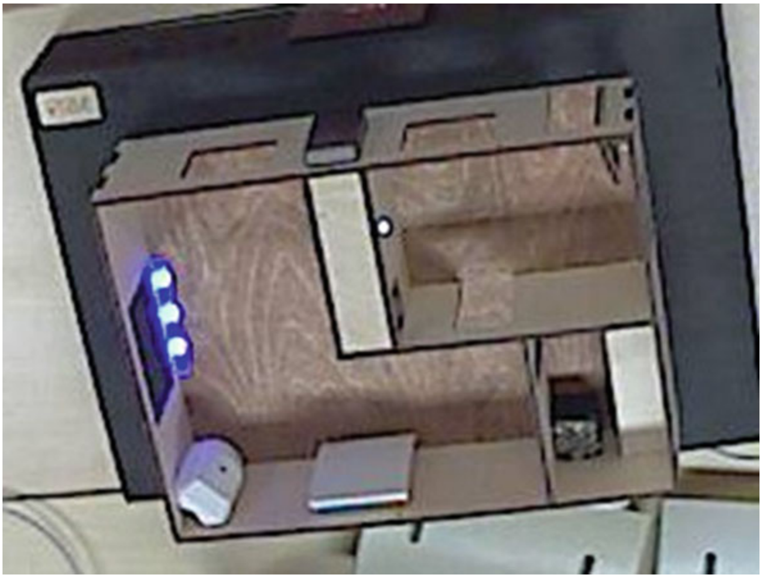

Fig. 4.3 House-scale model

- Integration Model: defines how other service utilities (systems) may be used from this service utility (e.g., integration with Enterprise Resource Planning systems).
- Organization Model: defines, who is responsible for what in the company.
- Security Model: defines the security infrastructure that should be put in place.
- Information and Data Model: defines the exchange of necessary information among different actors (humans, companies, and service utilities).

4.4 Teaching Smart House Solutions

In the previous parts of the chapter, we describe our approach principles and offer new solutions to problems. Now we use them for specific courses. The course, where we use the methodology, is called “Internet of things solutions: Smart

Fig. 4.4 House-scale model electronics

Devices, Processes and Services" [35]. Specifically, we create a serious game for a smart-house solution. The core of the game is a real smart-house solution [36]. Throughout the game, the situation is close to the actual one. Although the house model (wooden scale model, see Fig. 4.3) is used instead of a real house, everything else is genuine. House automation electronics (see Fig. 4.4) and supporting software are actually used in many industrial projects.

The computer interface to access the software is notably simple. For example, in Fig. 4.5, we can see the house model interface. Through this interface, we obtain the information from the sensors and the ability to run the actuators.

For more advanced settings, the appropriate interface is also set up (see Fig. 4.6). To present the historical data, a graphical interface is used (Fig. 4.7). Figure 4.8 presents a room climate data-setting screen.

Game situation modeling. Now we describe the game situation. The teacher prepares a series of descriptions of the possible conditions. Data updating is used to fix the situation on our server. For example, a severe decrease in weather is simulated outside the temperature changes in the context data. Then the student must make adequate decisions to manage the situation. The student's actions are captured, saved, and later analyzed by teacher.

The context in a smart house includes the home environmental conditions (temperature, humidity, and lighting) and information about the residents

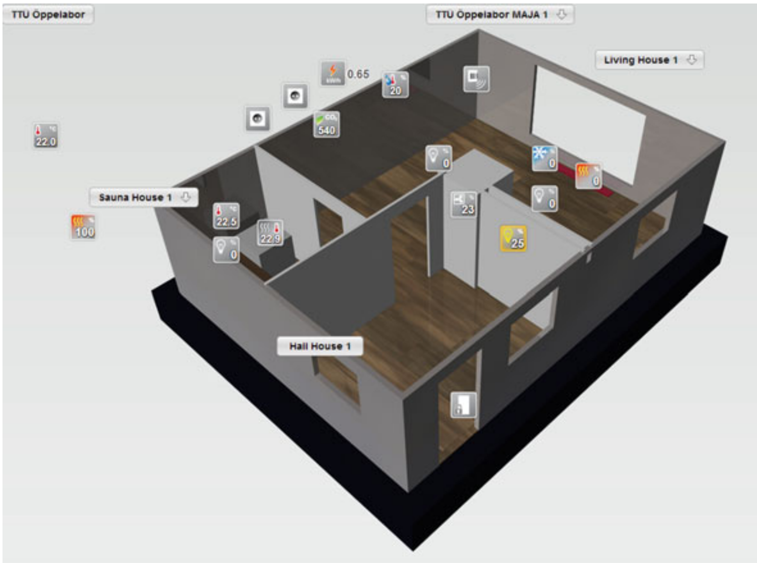

Fig. 4.5 House-scale model interface

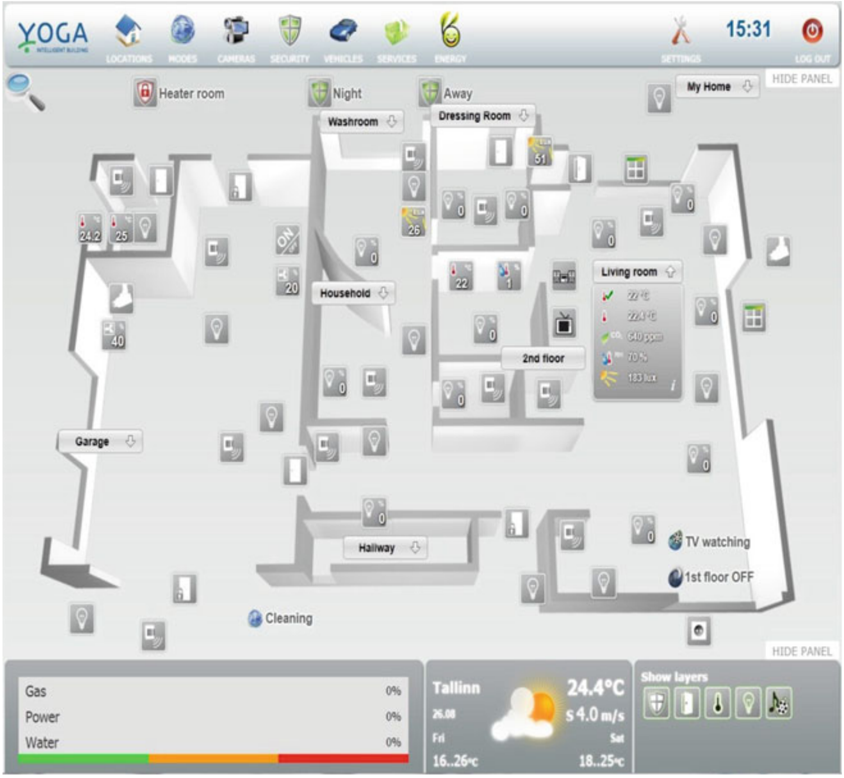

Fig. 4.6 House setting interface

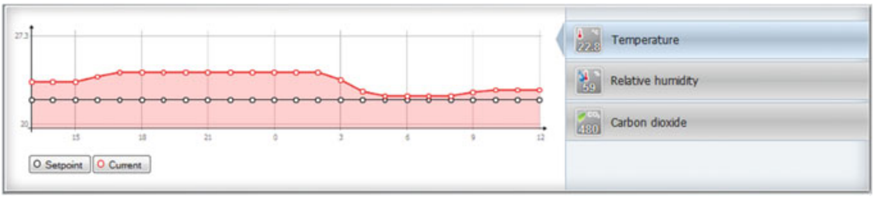

Fig. 4.7 Climate control example

(their location, mobility tracking, and behavior). The student's actions can be simple (switch heating on) or complex (described using business process description language BPMN). In Fig. 4.9, a simple business process description is presented. The student can create hundreds of these descriptions of business processes. In more complicated situations, pre-prepared process archetypes are used.

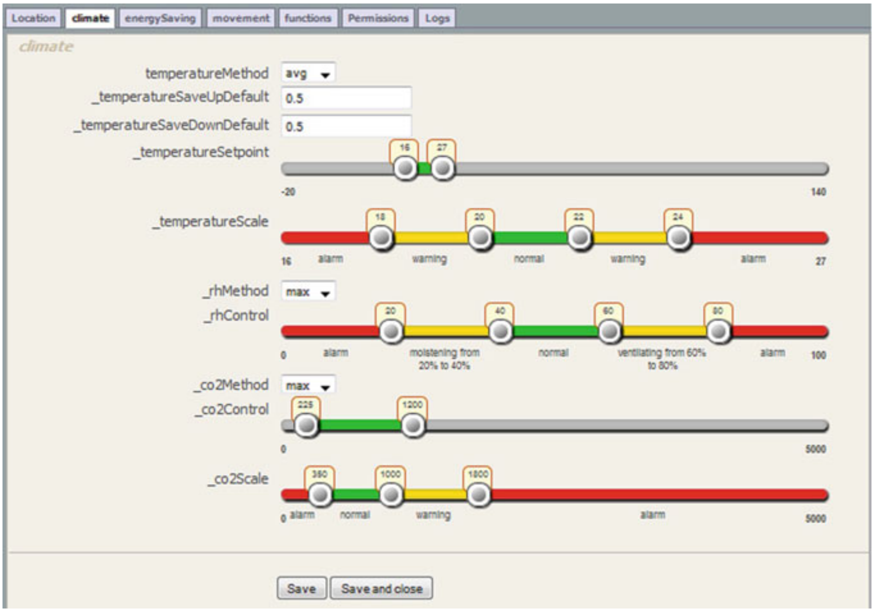

Fig. 4.8 Climate control setting

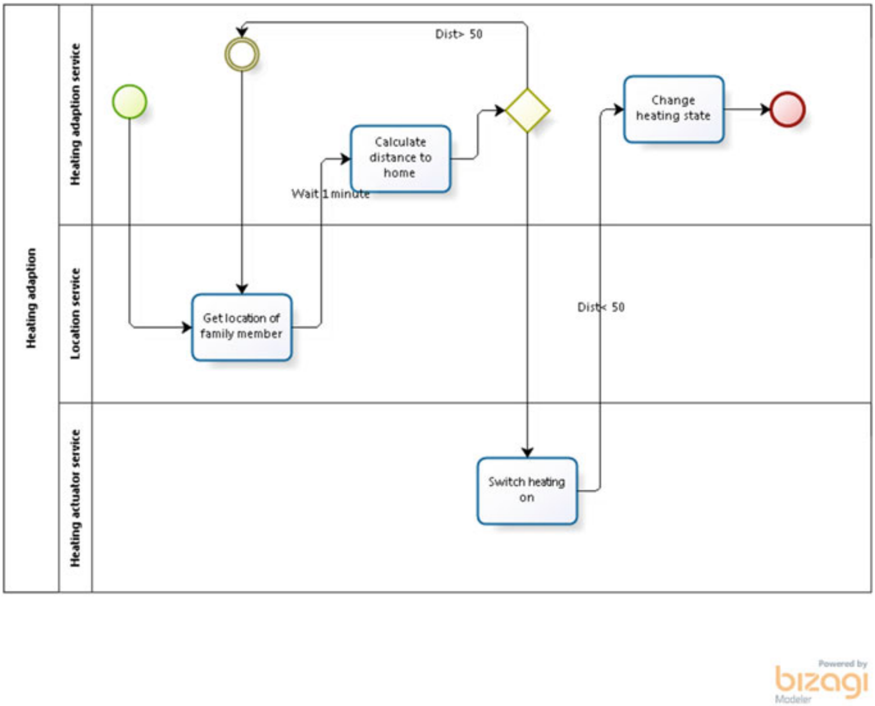

Fig. 4.9 Executable business process description model

4.5 Conclusions

We currently lack the simple tools to create serious games. This chapter proposes some solutions for the problem. First, the model-driven engineering approach can help solving this problem. Second, the use of patterns is also a notably promising direction. One of the challenges is that the domain, where we act, is also at the development stage; thus, we must address the domain model development in the field of internet of things.

Our future plan includes expanding the application areas of the internet of things (smart cities and smart governance). In addition, the area of self-organization will be investigated in further.

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Chapter 5
Evaluation of Student Knowledge Using an e-Learning Framework

Margarita Favorskaya, Yulya Kozlova, Jeffrey W. Tweedale and Lakhmi C. Jain

Abstract This chapter introduces the concept of adding a fuzzy logic classifier to e-Learning framework. This conceptual model uses Fuzzy Logic Evaluation Sub-systems (FLESs) to implement "Theory of probability" curriculum. The customized sub-system is used to dynamically evaluate student knowledge. It is essential that the FLES-PRobabilty (FLES-PR) capture's the students' interest to maintain their motivation and increase the effectiveness of the learning experience. Given that interactive systems increase the education efficiency and the individual abilities of student, the routine actions of teacher are must be delegated to e-Learning system. In this chapter, artificial intelligence concepts, techniques, and technologies are used to deliver the e-Learning requirements. For instance, a fuzzy logic scheme is created to evaluate student knowledge when using the FLES-PR. The curriculum is delivered using two FLES modules instantiated using the "Matlab" 6.5 fuzzy toolbox environment. Each sub-system provides structured lessons, representing topics, content, and additional contextual parameters. The FLES is designed to gain the students attention, highlights the lesson objective(s),

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stimulates recall of prior knowledge, and progressively elicits new material to guide increased performance by providing feedback using benign assessment to enhance retention. The proposed evaluation system is designed as a functioning plug-into the universities "Moodle" server to leverage from the existing course management, learning management and virtual learning environment. It also recommends the pace and complexity of learning as the student progresses through the curriculum. This chapter case study discusses the success of the FLES-PR software tool and explains how it has been validated against the manual results of three human experts.

Keywords Concept mapping · e-Learning · Fuzzy logic · Knowledge evaluation · Interactive system · Higher education

5.1 Introduction

Social media and virtual community applications continue to enhance computer literacy. The growing awareness of information streaming is also being accelerating with the evolution of the Bring Your Own Device (BYOD) products. Similarly, this new generation of tech-savvy students are now demanding better access to education remotely and at their convenience. The rapid growth of web resources and services has had a major influence on the education community. The current generation of students have the daily skills and knowledge to access many software tools, web resources, and social networks [1–3]. The Computer-Based Training (CBT) has evolved to include richer sources of multi-media and interactive learning material. More recently, the Intelligent Tutoring System (ITS), the CBT systems, and adaptive hypermedia have been widely used to development web-based courses [4]. These systems and individual motivational drivers are central to providing distance; a remote and external learning Serrano-Cámara et al. classify motivation as follows [5]:

- **Intrinsic** motivation is an important phenomenon and is used to achieve high-quality learning results.
- **Extrinsic** motivation is promoted through specifically identified internal regulation. The course goals are aimed at promoting increase engagement.
- **Psychology** motivation is focused on proving rewards that separate the tendency to avoid regulation for fear of punishment.
- **Amotive** motivation results in a fluctuating level of participation based on episodes of apathy or socially derived distractions.

The e-Learning systems provide easy access to learning material in a safe and flexible environment. Given on-line access, these knowledge warehouses now provide prospective students with learning opportunities any time and anywhere. This approach to learning attracts new students and aids in retaining current students. The on-going development of the BYOD products and wireless communication technology continues to provide more flexible or mobile learning (m-Learning). The same technology also facilitates group technology enabling, face-to-face or collaborative learning in a virtual environment [6]. This technology is also spreading to support industry and virtual conferencing [7]. These trends will continue as technology facilitates increased capability, therefore researchers must endeavour to provide more robust means of scalable assessment using methods like FLES.

This chapter is structured as follows. Section 5.2 provides a brief literature review in e-Learning systems while Sect. 5.3 includes a discussion about the conceptual model. Section 5.4 presents a the fuzzy logic classification scheme used to evaluate student knowledge. Section 5.5 describes FLES-PR system. Section 5.6 discusses the results of the test and validation process using three subject matter experts. Finally, Sect. 5.7 provides a summary and possibilities for future development.

5.2 Background

The e-Learning is not new, however it has shaped the way teachers deliver learning opportunities to students. Typically teachers try to demonstrate respect for their students, while building on their strengths by using their preferred learning styles in a classroom [8]. Achieving this remotely or on-line is often problematic and often isolates or delays feedback about the students learning style. Computers provide a one-to-one interface that provides feedback based on the software that operates the application. Pre-defined computer-based interactions must be resourcefully encoded using innovative applications that need to simulate the ability to work cooperatively and negotiate individualised learning. Pedagogical frameworks have evolved to support the ITS and the CBT using computer software [9]. These systems focused on specific learning goals by providing a digital representation (taxonomy) of the syllabus. The core activities were designed to facilitate [10]:

- Student-centred learning.
- Fostered competency-based expectations.
- Aligned curriculum objects and automated assessment.
- Invokes evidence-based decision-making.
- Provides targeted and structured instruction.
- Ultimately provides a safe, supportive, inclusive learning environment.

Regardless, a curriculum must be ordered (using a watershed design) and contain a full set of lessons relating to a specific topic. Stockinger and De Pablo believe that the Computer Assisted Learning (CAL) will contain components to implement a variety of remote training methods. These could include: structured warm-up activities, alternative presentation skills, reading material, virtual demonstrations, multi-media aids, note-taking, discussion, case studies and questionnaires [11].

They suggest using tools like; Authorware (Macromedia), IconAuthor (Asymetrix), and CourseBuilder (Discovery Systems) to assist in optimising the CBT content.

Conati and Manske reported the performance of the tools and methods used within the CBT ITS rely on the Artificial Intelligence (AI) techniques. They concluded that knowledge representation and programming techniques would be used to focus on delivering instructional content and support that is tailored to the individual [12]. Goldberg et al. recently identified a pedagogical design that included five adaptive training elements. These include: curriculum, instructional strategy, performance measures, pedagogical interventions, and a student data model [9]. Their Generalized Intelligent Framework for Tutoring (GIFT) system was based on the traditional sense, decide and action cycle. It also included a learning management system to maintain the curriculum and on-going student competency.

The e-Learning systems are more expensive to create than traditional curriculum; however, they are gain significant traction because they service people, who have issues attending conventional classroom training. They support learners, who are geographically dispersed, constrained by family commitments, limited by transportation, mobility, geopolitical conflict and even personality. “e-Learning can be defined as the use of computer to deliver a broad array of solutions to enable learning and improve performance” [13]. It can be tailored to deliver cognitive, interpersonal, and psychomotor skills across many domains. The delivery can also be configured to support self-paced, instructor, facilitator, and even “blended learning” [14]. Each application will typically provide components with content, tutoring, coaching, mentoring, and collaborative functionality to support the virtual classroom. A number of open source systems have evolved e-Learning Management System (e-LMS)[1] such as eFront,[2] Moodle,[3] Dokeo,[4] Claroline,[5] Ilias,[6] Sakai,[7] and Olat.[8] Moodle is being adopted by many universities including the Siberian State Aerospace University and the University of South Australia. These tools are distributed with a repository of tools to add functionality. There is also a growing community of practitioners, who are developing add-on components to extend in-built functionality. This should be modularised objects, learner-centred, provide a granular approach with engaging content that is interactive and tailored to the individual (personalised).

Wiley describes the content of e-learning in terms of atoms or manageable “chunks” called learning objects [15]. He describes how, until recently, a Lego block was mistakenly used as a metaphor to explain the simplicity of learning

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1 www.openelms.org/.

2 http://www.efrontlearning.net.

3 https://moodle.org.

4 http://www.dokeos.com.

5 http://www.claroline.net.

6 http://www.ilias.de.

7 http://www.sakaiproject.org.

8 http://www.olat.org.

objects. Govindasamy also suggests this approach is to simplistic and should be avoided [16]. Both state that Lego blocks are distinctly different from learning objects because [15]:

- Any Lego block can be joined with any other Lego block.
- Lego blocks can be assembled in any manner.
- Assembling Lego blocks are simple for children to assemble.

Unfortunately atoms are more complex because they don't all fit together, they are only attracted to atoms with mating structures and special skills are required to achieve the outcome. The e-Learning systems simplify this process but providing a collection of tools in component form that free course to focus on delivery. Moodle was originally made for education, training, and development environments to help educators create on-line courses that would focus on interaction and collaboration. There are over 50,000 registered users and the framework has recently been extended to support business. The environment is categorized based on its intended use. The key elements include the:

- Course Management System (CMS).
- Learning Management System (LMS).
- Virtual Learning Environment (VLE).

Moodle runs without modification on Unix, Windows, MacOS, and many other systems that support PHP scripting language and a database compliant with the Sharable Content Object Reference Model (SCORM)[9] and the Aviation Industry Computer-Based Training Committee (AICC)[10] standards. However, its installation requires certain technical proficiency of PHP technology [13]. It provides a suitable platform for researchers to improve components that enhance delivery. This chapter uses the Matlab fuzzy library[11] to design and test the Fuzzy Logic Evaluation Sub-systems—PRobability (FLES-PR) to implement a curriculum focused on "Theory of probability".

5.3 Existing Research

The volume of literature pertaining to the development of the CBT and e-Learning systems is substantial; therefore the authors focus on the key topics relating to developing the concept model and evaluation using fuzzy logic. Chrysafiadi and Virvou conducted an excellent review on this topic. It spans the past decade and catalogues the mental models used to represent students digitally [17]. These

[9] http://scorm.com/scorm-explained/.

[10] http://www.aicc.org/joomla/dev/.

[11] For Mathworks fuzzy logic toolbox documentation, see http://www.mathworks.com.au/help/fuzzy/functionlist.html.

commonly include: overlay, stereotype, perturbation, machine-based, cognitive, constraint-based, Bayesian, predictive, fuzzy and ontological student models. The most popular approaches uses the stereotypes, overlay, fuzzy, Bayesian networks, predictive model, and cognitive theory. For instance:

- The Adaptive Hypermedia System that integrates a Thinking Style (AHS-TS) using the overlay student model demonstrated by Mahnane et al. [18].
- A web-based adaptive learning system called PDinamet designed by Gaudioso et al. was used to teach physics in a secondary education [19].
- The ITS called DEPTHS combining a stereotype and an overlay model with the fuzzy rules [20] was designed to help students learn software design patterns.
- The INQPRO system, which predicts the acquisition of scientific inquiry using Bayesian networks [21].
- Finally Peña-Ayala et al. discuss a predictive model that can dynamically build the cognitive maps to set the fuzzy-causal relationships among the lecture's option properties and the student's attributes in web-based educational systems [22].

Cline et al. [23] proposed the ITS using a Concept Mapping Tool (CMT). This system automatically evaluates performance based on the maps provided by the instructor of a course. A typically the CMT includes the following components:

- An Applet written in Java language to assist the designer to draw the concept maps.[12]
- HTML Web pages used to dynamically generated content by using Java ServerPages.[13]
- A DBMS—in this case, using "MySQL".[14]
- An Expert System to implement the rule-based evaluation system such as JESS.[15]

The e-Learning system must be capable of monitoring and sharing knowledge successfully to be effective. Desmarais and Baker discuss a student's meta-cognitive model [24], and Fiorella et al. [25] show how planning, monitoring, and evaluation can be used to highlight how high levels of meta-cognitive function effect an individual learning (including e-Learning environment). Peña-Ayala also used activity theory to design the Adaptive e-Learning System (AeLS) [26]. The proposed framework for the AeLS includes: principles, architectures, and dynamic perspectives associated with activity theory within e-Learning system. The architecture considers three types of activities at various levels such as individual, collective, and network. To learn more, Desmarais and Baker provide a useful review of intelligent learning environments [27]. These systems all interact with students to

[12] See docs.oracle.com/javase/tutorial/deployment/applet/.

[13] See www.oracle.com/technetwork/java/javaee/jsp/.

[14] See www.mysql.com.

[15] See www-lium.univ-lemans.fr/lehuen/master1/clips/jess/jess61RC1man.pdf.

provide a customized (individual) learning experience. The first challenge is to transform the curriculum into a digital format. Most rely on existing ontologies, rules, and structures similar to those systems listed above. Lesson or topic information is initially populated by subject matter expert knowledge (typically experienced lecturers). When deployed, the delivery is customized based on individual performance parameters that evolve over time. In this chapter, the authors show how the FLES framework can be used to analyze, model, and study the human praxis and how the "Moodle" AeLS is used to deliver the "Theory of probability" curriculum.

Most Artificial Intelligence (AI) applications use classifiers to either divide (segregate data) or control the flow of learning parameters. They can also be used to pre-process data into categories, prior to inferring any further action(s) [28]. The most popular techniques include: random forest, Neural Networks (NNs), Support Vector Machines (SVMs), k-nearest neighbour, Bayes, Decision Trees, and Fuzzy Logic. The system designer will select, which technique is appropriate based on the desired performance, efficiency, and the type of data being prosecuted [29].

In 1965 Zadeh defines the fuzzy logic as a form of logic based on graded or qualified statements in lieu of crisp values that are strictly true or false [30, 31]. In 1972, Zadeh introduced conventional techniques to analysis behaviour that is strongly influenced by human judgment, perception, and emotions [32]. Fuzzy logic enables membership to partial sets in lieu of existing crisp variables or non-membership. Zadeh believed that people operate using linguistic variables to manage groups of crisp sets to represent infinite valued logic [33]. For instance, when driving a car, they go faster or slower. They accept noise or imprecise inputs using membership functions to approximate a range of crisp sets. Sugeno subsequently implemented a fuzzy inference system capable of goal reaching functionality that was reviewed by error data at each range interval [34]. Fuzzy logic has been used to solve a variety of problems [35] such as classification [36], modelling [37] industrial controllers [38], and e-learning, for instance:

- Bai and Chen [39] used fuzzy logic to create an automated method for grading.
- Jia et al. [40] created adaptive learning system based on fuzzy set theory
- Taylan and Karagözoglu [41] developed the Adaptive Neuro-Fuzzy Inference System (ANFIS) to evaluate the Student Academic Performance (SAP) using a Sugeno fuzzy model to achieve clustering.
- Dias and Diniz [42] developed the Fuzzy Quality of Interaction (FuzzyQoI) with three cascading sets of five fuzzy inference systems.
- Lo et al. [43] proposed an adaptive web-based learning system based on students' cognitive styles.
- Millán et al. [44] created a Bayesian network to student model engineering.
- Tourtoglou and Virvou [45] used Simulated Annealing to promote collaborative learning between both for trainers and trainees using UML.

The FLES application uses fuzzy logic to evaluate student knowledge based on the linguistic variables, fuzzy membership functions, and a set of fuzzy rules.

5.4 Knowledge Evaluation Based on Fuzzy Logic

Membership functions are used for representation of linguistic groups of crisp sets. Fuzzy modelling is considered as a process of applying to specific systems or problems. In recent years, fuzzy modelling has increasingly been used to solve control and decision-making problems. A traditional fuzzy logic system differs from a traditional control system, when it uses knowledge provided by experts to build rules that express a logic using linguistic variables. A fuzzy variable is described by a set of three parameters (α, *X*, *A*), where α is a name of fuzzy variable, *X* is a set of α definition, and *A* is a fuzzy set on *X* set describing a restriction $\mu_A(X)$ on value of fuzzy α variable [46]. Here, a linguistic variable (β) is a set comprising of four tuples (β, *T*, *X*, *G*, *M*), where *T* is a defined set of fuzzy linguistic variables (term-set) with *X* as a definition area, *G* is a syntactic procedure used to work with elements of the *T* term-set (for example, a generation of new terms) [47], and *M* is also considered a semantic procedure, which is used to transform each crisp value to a linguistic variable as a result of *G*.

A fuzzy control system includes three main stages. These stages include fuzzification, inference (decision making unit and its contextual rules) and defuzzificaiton as shown in Fig. 5.1:

- **Fuzzification** involves a transformation of crisp input values into linguistic variables. It is possible that a value could be owned by several sets although it will have a degree of membership, based on rules, and, like the tipping problem, the maximum value is chosen.
- **Fuzzy Inference** is realized using a pre-conceived set of rules to derive a linguistic output based on the degree of membership. The concept is shown in Fig. 5.2. Given two inputs are applied to three deciding tuples. In parallel, a single crisp output can be generated.
- **Defuzzification** transforms the fuzzy derivatives to a crisp output based on the membership assigned during the inference process. The simplest transformation

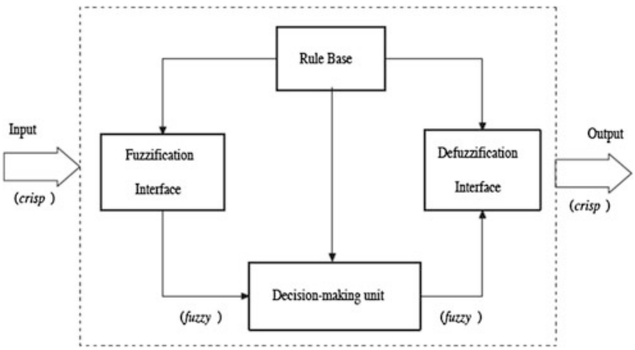

Fig. 5.1 Basic configuration of fuzzy logic system [48]

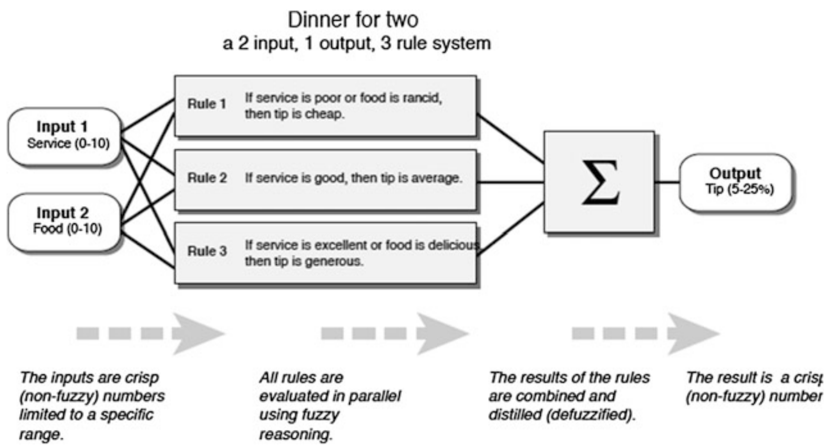

Fig. 5.2 Basic scheme of fuzzy inference [48]

is typically assigned the "first maximum". Common alternate variants could use the "center of gravity", "middle maximum", or a "de-fuzzified height".

The design of fuzzy logic system involves creating one or more sets containing linguistic variables and their associated rules. The direct approach employs expert estimations although computational techniques can be used to determine the relative frequency of data elements and possible membership values. An expert will typically structure rules based on own understanding and how other might perceive them. The FLES provides a knowledge evaluation system based on fuzzy logic to control learning tasks. A feedback system is included to direct the flow and provide estimates of the student success while learning. The conceptual scheme used to develop this knowledge evaluation system is presented in Fig. 5.3.

This system implements three interfacing strategies based on fuzzy logic such as task selection (Sect. 5.4.1), evaluation (Sect. 5.4.2), and prompts to help students acquire knowledge (Sect. 5.4.3).

5.4.1 Strategy for Task Selection

The goal of the strategy for task selection is to maximise the system efficiency, when determining the next element of the curriculum the current student needs to complete based on the subject set. This efficiency can be defined using two factors. They include the students' progression and total size of the topic sub-set. Therefore, the quantity of topic sub-set needs to be balanced by both size and difficulty. The level of tasks should progressively escalate in order for the student to save time and maximise their effort. Similarly the set should be structured to enable the system to estimate a students' knowledge with minimal repetition. Therefore, a smaller set of

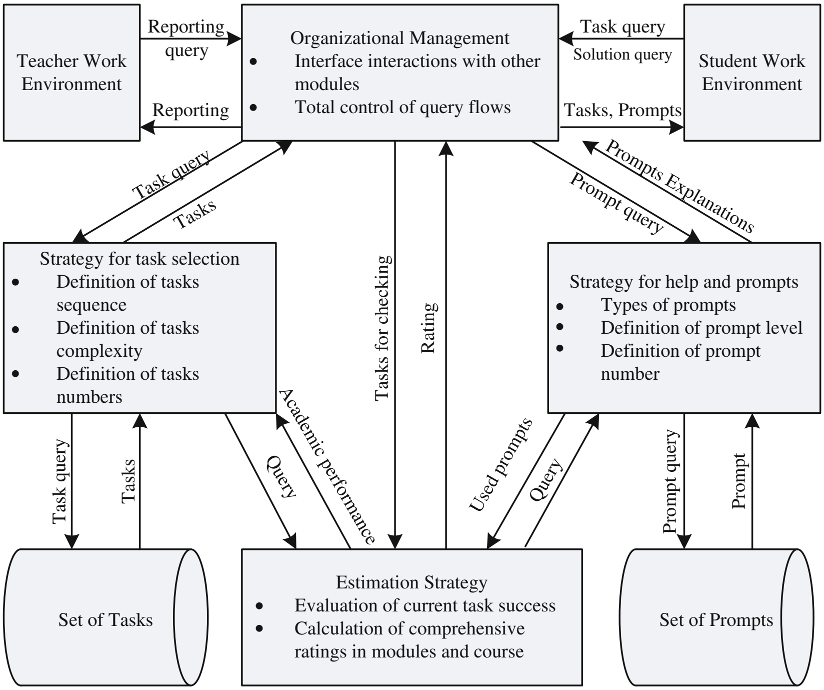

Fig. 5.3 The conceptual scheme of knowledge evaluation system

complex tasks can be presented to successful students, while a more extensive set of tasks that gradually increases in complexity is offered to less successful students.

The strategy of tasks selection involves creation of tasks sequence, assignment of complexity level of current task, and definition of numbers of tasks. The teacher makes a decision on relevance of task selection in current topic, course module, or whole course. This strategy is implemented by a set of rules reflected the methodology, which is used by the teacher.

As an example set of rules to define the strategy that defines the level of complexity for a specific task is explained using the following five rules:

IF (number_successful_scores = "small") THEN (student_status = "unknown").
IF (number_non-successful_scores = "large") THEN (student_status = "non-successful").
IF (number_successful_scores = "large") OR (number_non-successful_scores = "small") THEN (student_status = "successful").
IF (student_status = "non-successful") OR (student_status = "unknown")THEN (level_current_task = "simple").
IF (student_status = "successful") THEN (level_current_task = "complex").

During this definition, the tasks' sequence is also controlled to ensure the student builds concrete knowledge. This is achieved using the following fuzzy rules:

IF (student_solves_current_tasks = "poor") THEN (current_task = "back_to_previous_topic").
IF (student_solves_current_tasks = "good") THEN (current_task = "go_to-following_topic").

Two linguistic variables (good and poor) are used to test the students' ability to solve the current task. Membership for the current task is sequentially assigned based on the values "poor" and "good". These values are used to guide the system to proceed with the next topic or return to the previous topic to re-enforced the concept being taught, for instance:

IF (student_solves_current_tasks = "poor") THEN (number_tasks = "increase").
IF (student_solves_current_tasks = "good") THEN (number_tasks = "decrease").

5.4.2 Evaluation Strategy

The evaluation strategy involves two sub-strategies: the evaluation of current task and the comprehensive evaluation of course module. In the first strategy, each type of task requires the own evaluation procedure. Where the membership is a degree of the students answer to the correct answer as a result of current task evaluation. Therefore, the following evaluations may be applied to different types of elements mentioned in Sect. 5.3:

- Menu—a simple enumeration of menu items.
- Calculation—an estimation in any metric, for example, Euclidean.
- Word—an enumeration of answer variants or a semantic evaluation by usage any metric.
- Sentence—a semantic evaluation by use of any metric.
- Equation—a number of operations required for correct equation transform.
- Correspondence—a number of correspondences.
- "Hot" points—an estimation in any metric, for example, Euclidean.
- Sequence—the result can be presented as hierarchical oriented graph (tree); therefore, a nodes and edges superposition of graphs.
- Hypertext—a text semantic evaluation.
- Sound—can be applied previous evaluation types according of task context.

Each of estimations mentioned above includes a number of task and fuzzy membership degree to correct answer.

In the second strategy, it is required to build a comprehensive evaluation of course module. However, the use of fuzzy evaluations for current tasks is not suitable for receiving the clear teacher score. Let us introduce the following set of fuzzy rules:

IF (number of correct answers = “large”) THEN (score = “high”).
IF (number of correct answers = “small”) THEN (score = “low”).
IF (number of prompts = “large”) THEN (score = “low”).
IF (number of prompts = “small”) THEN (score = “high”).

As a result, a fuzzy set will be received instead of fuzzy numbers. Therefore, a correspondence between a fuzzy set and a fuzzy number of correct answers ought to be defined. It may be a simple sum of memberships or weighted sum of memberships for all tasks provided by Eq. 5.1, where x_i is a ith task in a module, $\mu(x_i)$ is a membership of ith task answer to correct answer, k_i is a weighted coefficient of ith task, N is a task number in a module, μ is a membership of fuzzy set $\mu(x)$ to large number of solved correctly tasks.

$$\mu = \frac{\sum_{i=1}^{N} k_i \, \mu(x_i)}{N} \tag{5.1}$$

A membership of fuzzy set $\mu(x)$ to a small number of solved correctly tasks $\bar{\mu}$ is determined by Eq. 5.2.

$$\overline{\mu} = 1 - \mu \tag{5.2}$$

In complex cases, the multi-dimension fuzzy set can be introduced. The dimension of such set will be a number of tasks, and a membership function will define its membership to large number of solved correctly tasks. Based on the received estimations, fuzzy rules, and linguistic variables, a fuzzy module evaluation can be executed.

5.4.3 *Strategy of Help and Prompts*

The strategy of help and prompts includes the definition of prompt types, levels, and numbers. On the one hand, such prompts ought to be understandable for a student and help to solve the task. On the other hand, they could not include an explicit answer. Such prompts are generated by experienced teaches, for example:

IF (number_prompts = “small”) THEN (prompt = “non-deep”).
IF (number_prompts = “large”) THEN (prompt = “deep”).

Also non-fuzzy rules can be introduced as a partial case of fuzzy rules, for example:

(number_prompts < 6).
IF (number_prompts = 6) THEN (show_solution).

Based on fuzzy rules and linguistic variables, the prompt types, levels, and numbers can be determined.

5.5 Conceptual Model of Course "Theory of Probability"

Let us consider the practical realization of course "Theory of probability" reducing it by three topics for better representation of test results processing such as module 1 "Classical definition of probability", module 2 "The basis of probability theory", and module 3 "Theorems for probability calculus". Each topic is a separate module with own five test tasks. The tasks are presented for a student with increased complexity. A student can ask a prompt.

In module 1 "Classical definition of probability", the basis of combinatorics is learned, and a definition of probability is introduced. The skills provided by this module are used in other modules. Five following tasks are represented into it:

Task 1. Any two-digit number is thought. It is required to find a probability that a random two-digit number is a pre-determined number.
Task 2. Two dice are broken. It is required to find a probability that a digit sum in the shown sides is even, and a digit "six" will be at least on one of two dice sides.
Task 3. Let 5 cards are randomly extracted from a 36 card batch. It is required to find a probability that all cards have red color.
Task 4. Let 5 cards are randomly extracted from a 36 card batch. It is required to find a probability that two aces are among them.
Task 5. Let 5 cards are randomly extracted from a 36 card batch. It is required to find a probability that one jack is among them.

In module 2 "The basis of probability theory", the main terms are introduced such as a space of elemental events, an elemental outcome, an event of probability, an impossible event, etc. The main combinations from elemental events are studied. In tasks 1–5, it is required to introduce the elemental events and state event A through them. Let a rifleman had three shots.

Task 1 A = {"A rifleman had one successful shot"}.
Task 2 A = {"A rifleman had two successful shots"}.
Task 3 A = {"A rifleman had at least one successful shot"}.
Task 4 A = {"A rifleman had at least one unsuccessful shot"}.
Task 5 A = {"A rifleman had at least two successful shots"}.

In module 3 "Theorems for probability calculus", the theorems of probabilities adding and multiplying, a term of conditional probability, the dependent and independent events are introduced. It is required to study modules 1 and 2 for successful learning of module 3. In tasks 1–5, it is necessary to express an event probability A through probabilities of elemental outcomes. Let a rifleman have three shots. The probability by one successful shot is equal 0.7. Other shots are independent events.

Task 1 A = {"A rifleman had one successful shot"}.
Task 2 A = {"A rifleman had two successful shots"}.
Task 3 A = {"A rifleman had at least one successful shot"}.

Task 4 A = {"A rifleman had at least one unsuccessful shot"}.
Task 5 A = {"A rifleman had at least two successful shots"}.

A student introduces a symbolic expression, which is a main formula for a task. Then a calculation is started. The summarized answer is a probability value or the used formula, if a calculation is not required.

For all represented tasks, three levels of prompts are supported:

- Level 1. The topic, for which a current task is situated, is pointed for a student. In most cases, this is enough. A student learns the topic and examples and solves a task.
- Level 2. The main formulas for current task solving are prompted for a student. A student learns them and solves a task.
- Level 3. A full solving of task with comments is represented for a student.

For tasks evaluation, the following test scheme was suggested in order to compare the results provided by Fuzzy Logic Evaluation System (FLES) with the experts' evaluation. Three FLESs were introduced for increasing of results reliability:

- The first level FLES (FLES1). A single task is estimated by a pre-determined teacher score, if a task was solved correct. A score is decreased, if errors took place or prompts were used.
- The second level FLES (FLES2). A module is estimated by the own scaled score. A module evaluation is not a simple addition of tasks scores. A module is estimated as a comprehensive and finite set of knowledge.
- The third level FLES (FLES3). A whole course is estimated as a finite set of knowledge, and such evaluation also is not a simple addition of all modules scores.

The proposed approach for knowledge evaluation is differed from the used systems in order to evaluate the weak formalized fuzzy factors as an attempt for simulation of expert evaluations.

5.6 Fuzzy Logic Evaluation System-PRobability (FLES-PR)

Our efforts were directed on FLES creation into "Matlab" 6.5 environment [49]. As an example, the course "Theory of Probability" was used. The FLES-PR was designed as a hierarchical system of fuzzy derivation, which is presented in Fig. 5.4.

The FLES-PR system includes three levels. The fuzzy controller of first level FLES1 estimates a quality of the solved tasks and analyzes the errors and the used prompts. The fuzzy controller of second level FLES2 provides a quality evaluation of module learning. The fuzzy controller of third level FLES3 evaluates a quality of whole course learning. Each level of fuzzy controller includes two global tasks. The first task is a creation of linguistic parameters by the expert's help. The second task is a design of fuzzy rules base, which contains the expert's reasoning and a structure

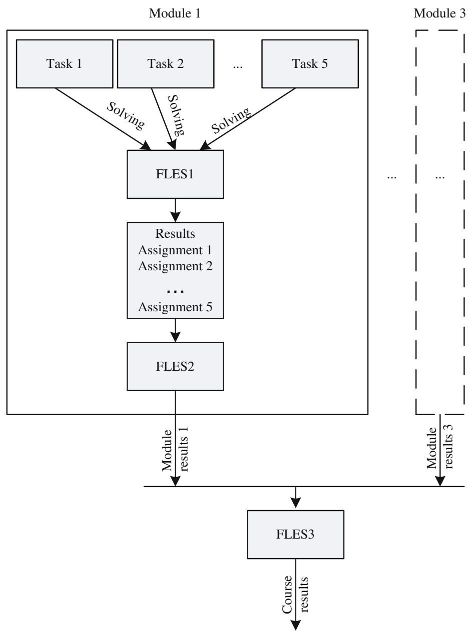

Fig. 5.4 The hierarchical system of fuzzy derivation FLES-PR

of knowledge domain. The work of fuzzy controllers FLES1, FLES2, and FLES3 are described in Sects. 5.6.1, 5.6.2, and 5.6.3, respectively. Section 5.6.4 indicates some test results of FLES-PR application.

5.6.1 Definition of Linguistic Variables and Fuzzy Rules in FLES1

Let us consider a set of linguistic variables and then a fuzzy rules base, which are used into a fuzzy controller FLES1. Three linguistic variables were introduced such as “Type_error”, “Prompt_level”, and “Task_rating”:

- Linguistic variable “Type_error” is based on the typical errors. According to three types of errors including a calculation error, an error in a formula, and error in a formula choice, three values of linguistic variable “Type_Error” can be represented as “minor”, “major”, and “rough”.
- Linguistic variable “Prompt_level” uses three levels of prompts (Sect. 5.5). Therefore, “level 1”, “level 2”, and “level 3” are values of this linguistic variable.
- Linguistic variable “Task_rating” is the output of fuzzy controller FLES1, which has values “low”, “middle”, and “high”.

Semantics of the FLES1 linguistic variables are situated in Fig. 5.5.

For the fuzzy controller FLES1, the following fuzzy rules were designed:

IF (Type_error = "minor") AND (Prompt_level = "level 1") THEN (Task_rating = "high").
IF (Type_error = "minor') AND (Prompt_level = "level 2") THEN (Task_rating = "middle").
IF (Type_error = "minor") AND (Prompt_level = "level 3") THEN (Task_rating = "low").
IF (Type_error = "major') AND (Prompt_level = "level 1") THEN (Task_rating = "middle").
IF (Type_error = "major") AND (Prompt_level = "level 2") THEN (Task_rating = "low").
IF (Type_error = "major") AND (Prompt_level = "level 3") THEN (Task_rating = "low").
IF (Type_error = "rough") AND (Prompt_level = "level 1") THEN (Task_rating = "low").
IF (Type_error = "rough") AND (Prompt_level = "level 2") THEN (Task_rating = "low").
IF (Type_error = "rough") AND (Prompt_level = "level 3") THEN (Task_rating = "low").

A screen of the FLES1 is represented in Fig. 5.6, which illustrates a case, when a student had not any error but used a prompt of level 2. Numbers 1–9 are the numbers of rules, according to which a fuzzy derivation is formed. Task rating is equal 15.5 that correspond to a "satisfactory" score.

5.6.2 Definition of Linguistic Variables and Fuzzy Rules in FLES2

For fuzzy controller FLES2, following linguistic variables were introduced:

- Linguistic variable "Number_correct_answers" has two values "small" and "large".

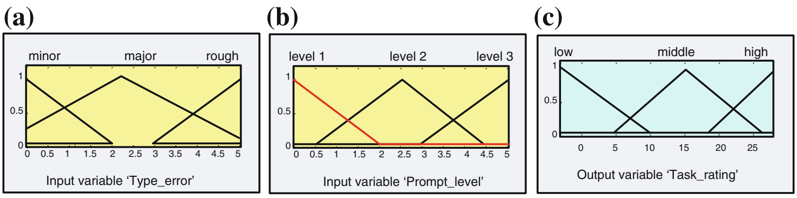

Fig. 5.5 Semantics of the FLES1 linguistic variables: **a** input variable "Type_error", **b** input variable "Prompt_error", **c** output variable "Task_rating"

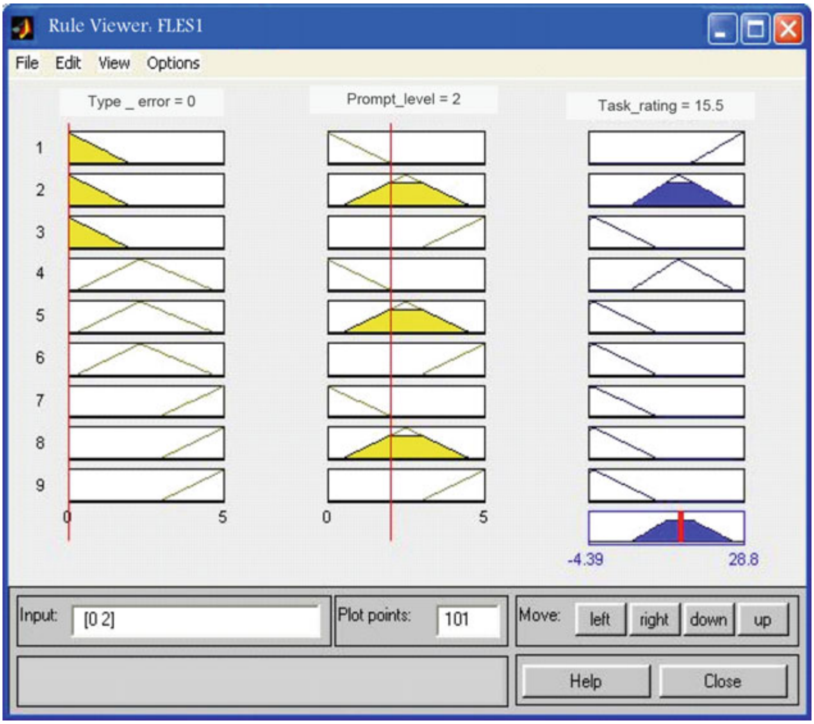

Fig. 5.6 Screen of the FLES1

- Linguistic variable “Number_prompts” involves number and level of the used prompts. Values of this linguistic variable are “small” and “large”.
- Linguistic variable “Evaluation_module” is the output of fuzzy controller FLES2 with values “low”, “middle”, and “high”. A value of this linguistic variable is into interval [0…25].

Semantics of the FLES2 linguistic variables are presented in Fig. 5.7.

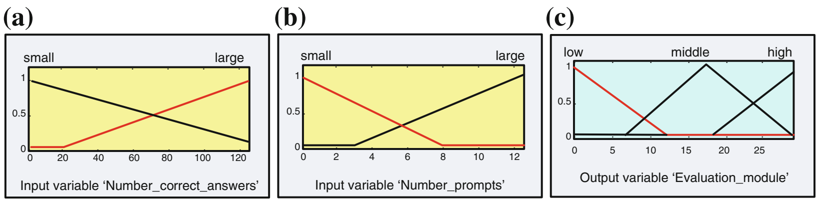

Fig. 5.7 Semantics of the FLES2 linguistic variables: **a** input variable “Number_correct_answers”, **b** input variable “Number_prompts”, **c** output variable “Evaluation_module”

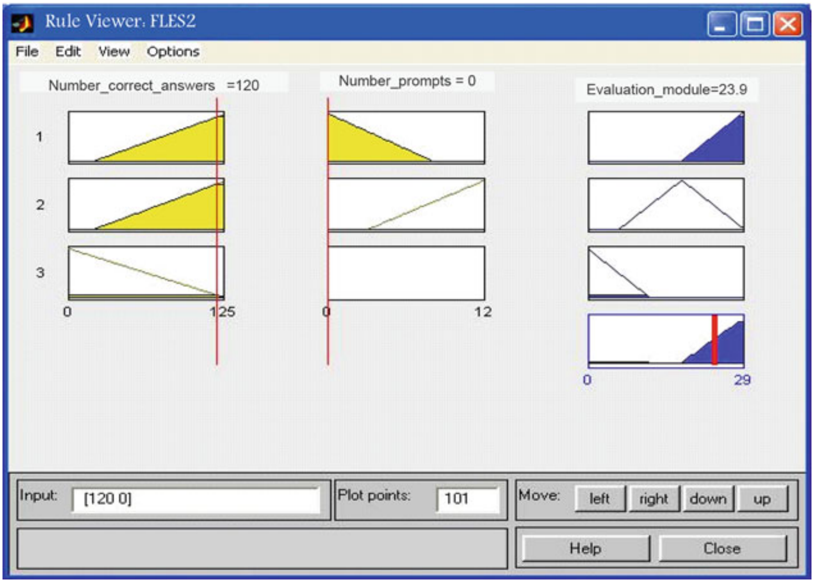

Fig. 5.8 Screen of the FLES2

The following fuzzy rules are used for the FLES2:

IF (Number_correct_answers = "large") AND (Number_prompts = "small") THEN (Evaluation_module = "high").
IF (Number_correct_answers = "large") AND (Number_prompts = "large") THEN (Evaluation_module = "middle").
IF (Number_correct_answers = "small") THEN (Evaluation_module = "low").

A screen of the FLES2 is show in Fig. 5.8 for a case, when a student made a calculation error in one task and did not use any prompt. The estimation of module is equal 23.9.

5.6.3 *Definition of Linguistic Variables and Fuzzy Rules in FLES3*

Three linguistic variables were proposed for fuzzy controller FLES3:

- Linguistic variable "Total_number_correct_answers' summarizes the numbers of correct answers from all modules and has two values "small" and "large".
- Linguistic variable "Total_number_prompts" summarizes the numbers of prompts from all modules. Values of this linguistic variable are "small" and "large".

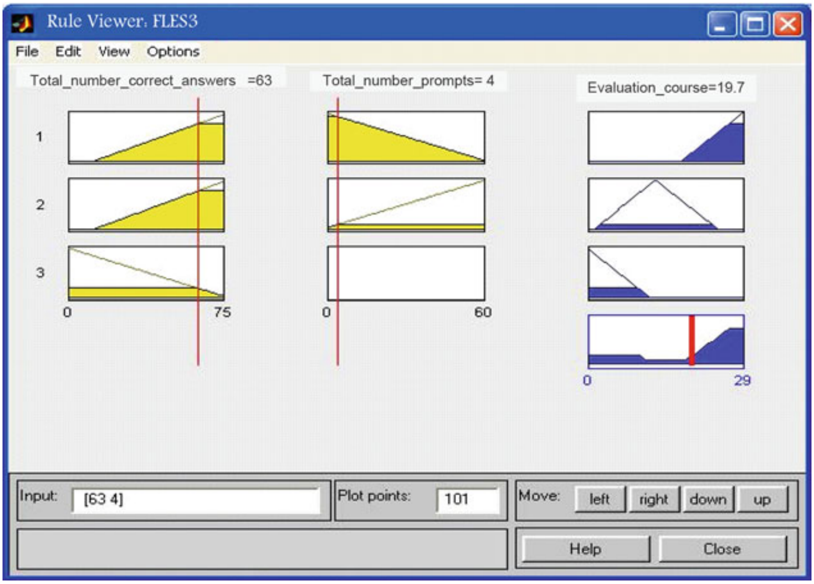

Fig. 5.9 Screen of the FLES3

- Linguistic variable “Evaluation_course” is the output of fuzzy controller FLES3 with values “low”, “middle”, and “high”.

The fuzzy rules for the FLES3 are similar to the fuzzy rules for the FLES2. Figure 5.9 provides a screen of the FLES3.

5.6.4 Test Results of “FLES-PR”

Into experiments, 26 students were involved. For simplifier presentation of receiving results, let us consider a methodology applied for three students’ evaluation. Student 1 is a successful student, who makes small number of errors. Student 2 is a good student, who solves the tasks by using prompts and help of the teacher. Student 3 is a non-successful student, who makes large number of errors and uses prompts. The set of tasks represented in Sect. 5.5 was used into this experiment. Short description of test results is situated in Table 5.1.

The results from Table 5.1 were the input data for FLES-PR system, and also they were represented for three university teachers. All evaluations were normalized to score 25 at the level of task, the level of module, and the level of course. The results for all three students were also tabulated using the same layout and then graphed. Figure 5.10 shows the results for students 2 and 3 (where student 1 was similar to student 2).

Table 5.1 Description of test results of three students

Task	Student 1	Student 2	Student 3
Module 1			
Task 1	Right	Right	Right
Task 2	Right	Right	Prompt of level 2
Task 3	Calculation error	Calculation error	Calculation error
Task 4	Right	Prompt of level 1	Prompt of level 1
Task 5	Right	Prompt of level 1	Prompt of level 2
Module 2			
Task 1	Right	Right	Incorrect formula
Task 2	Right	Incorrect formula	Incorrect formula
Task 3	Right	Prompt of level 2	Prompt of level 2
Task 4	Right	Right	Right
Task 5	Right	Right	Right
Module 3			
Task 1	Right	Right	Prompt of level 2
Task 2	Right	Right	Right
Task 3	Right	Right	Prompt of level 1
Task 4	Calculation error	Calculation error	Calculation error
Task 5	Right	Right	Calculation error

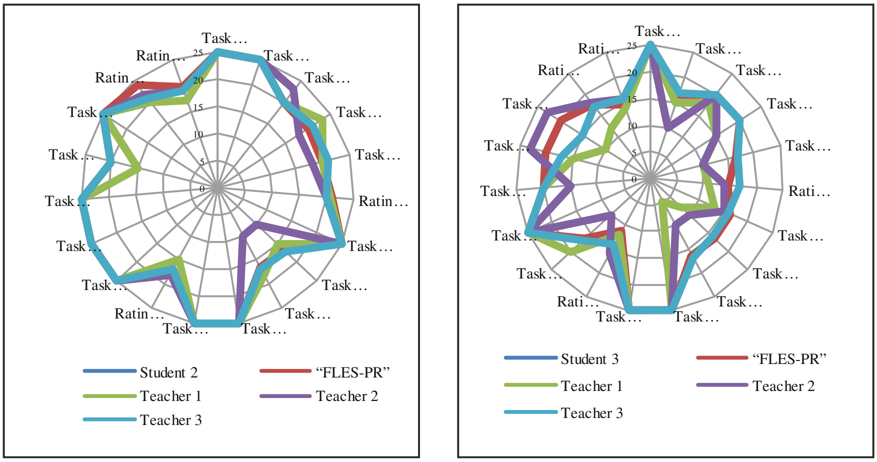

Fig. 5.10 Screen of the FLES3

Teacher 1 has a strong bias on Task 2.2, scoring all three students lower in all instances. Similarly Teacher 2 has a small bias on Task 1.2 and 3.4, however overall FRES-PR provides an excellent correlation for the initial settings (Fig. 5.11). Over time, further validation will enable fine-tuning to improve the overall results.

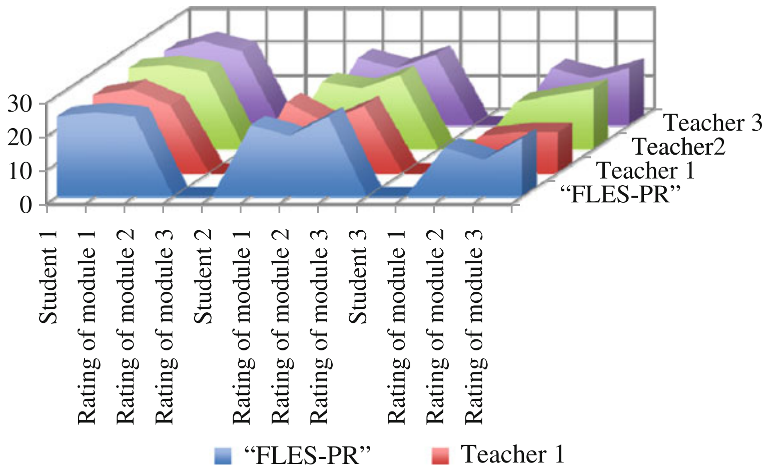

Fig. 5.11 Screen of the FLES3

The data verifies that FLES-PR makes good decisions and this was validated based on the experts' evaluations. The maximum deviation of each expert is within a standard deviation and considered within the variation of individual estimations made by each teachers. However, these deviations are decreased in module evaluations, and a whole course is evaluated with a variety 2 in a 25 score interval. Such variety can be considered as the independent. The received results prove the possibility for the usage of the proposed fuzzy logic knowledge evaluation in e-Learning university practice.

5.7 Conclusion

In this chapter, the conceptual model of e-Learning framework was developed as a set of related preparation, study, evaluation, and adaptation processes. A knowledge evaluation system based on the fuzzy logic controllers was the object of automation, which controls the tasks and the solved tasks flows, and also estimates the student success during the course learning. The conceptual scheme of knowledge evaluation system was represented, which realizes three interfacing strategies based on fuzzy logic such as the strategy for task selection, the evaluation strategy, and the strategy of help and prompts.

Our contribution connects with a fuzzy logic application FLES, which includes three levels. The fuzzy controller of first level FLES1 estimates a quality of the solved task and analyzes the errors and the used prompts. The fuzzy controller of second level FLES2 provides a quality evaluation of module learning. The fuzzy controller of third level FLES3 evaluates a quality of whole course learning. For each level, the linguistic variables by the expert's help and a rules base were created.

The hierarchical system of fuzzy derivation FLES-PR for course "Theory of probability" was design into "Matlab" 6.5 environment. This software tool works under the management of e-Learning university server "Moodle" providing all transmission functions between a student and a teacher. The real tasks from the course "Theory of probability" were represented for the students. The received by FLES-PR scores were compared with the expert's recommendations, and provided a variety 2 in a 25 score interval. These estimations permit to hope that other university courses based on the FLES core can be automated for the e-Learning distance interactions. Also the management sub-system realization needs in some functional improvements.

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Chapter 6
The iTEC Eduteka

Luis Anido, Frans van Assche, Jean-Noël Colin, Will Ellis, Dai Griffiths and Bernd Simon

Abstract In the current panorama of education across Europe we find that technology is increasingly present in the classroom. On the one hand, we have government programs that provide classrooms with a technological infrastructure. On the other hand, students themselves, usually have mobile devices—such as smartphones and tablets—and carry them everywhere, including the classroom. In this context, it is born the Innovative Technologies for an Engaging Classroom (iTEC) project, which is the flagship FP7 project in the education area, financed by the European Commission with 12 million Euros. The iTEC tries to contribute to the conception of the classroom of the future, in which technology is complemented with the most innovative pedagogical approaches, which entail a major level of dynamism in the educational practice. Thus, the iTEC promotes an educational

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practice, in which students interact in small projects including a participation in events, speeches with experts, and all that seasoned with the use of technology. In the iTEC, The Eduteka is a toolkit of technologies for advanced learning activity design. The components of the Eduteka provide support for the iTEC pedagogical approach. Those are thoroughly presented in this chapter.

Keywords Innovative technologies · Higher education · Future classroom scenarios · Eduteka · Learning activities · Scenario development environment

6.1 The iTEC—Designing the Future Classroom

The iTEC was a 4 year, large-scale project that took an informed look at the potential classroom of the future. The project was part funded by the European Commission under the FP7 programme and ran from September 2010 to August 2014.

The iTEC set out to bring together policy makers, researchers, technology suppliers, other technology-enhanced learning experts and innovative teachers in order to design and build scalable learning and teaching scenarios as realistic visions for the future classroom. These future classroom scenarios describe innovative, engaging and inspiring approaches to learning involving advanced teaching practices supported by effective use of technology. Rigorous testing of these future classroom scenarios in large-scale pilots across Europe was carried out in order to support the development of a sustainable, wider scale adoption of innovation in European schools. The iTEC learning centred approach is based upon an understanding that technology in itself cannot bring about the advancements in learning and teaching needed by European citizens, society, and the economy, without consideration of other factors such as vision, teacher competencies, the learner experience, and the usability and deployment of technology.

With a Consortium of 27 project partners, including 14 Ministries of Education, and funding from the European Commission of 9.45 million Euros, the iTEC was like no other project of its kind in terms of its scope and scale of ambition. This ambition, simply put, was to build upon the current knowledge base regarding research and practice in the deployment of technology across education in order to provide a blueprint for the future classroom.

During the project, the iTEC Consortium developed a set of processes and tools designed to help school leaders, teachers and other education specialists rethink the current use of Innovative Computer Technologies (ICTs). The concrete guidance and tools have been developed to help close, what is increasing being called, the "mainstreaming gap", where technology is not yet fully harnessed as a systemic part of everyday classroom practice that integrates learning both in and out of school. These tools and processes have been packaged together as a "toolkit" called Eduvista+, intended to support this approach and "allow schools to seize the future", according to one ministry involved in the project. They do this by: analysing trends and challenges; comparing how well the school is exploiting ICT by using an innovation maturity model; and helping schools to design innovative Learning Activities that encourage both teachers and learners to move out of their comfort zones. Crucially, the iTEC process, supported by this toolkit, makes the educational expert such as the teacher, the agent and designer not the object of change. They empower schools by providing a framework for experimentation that allows teachers a degree of risk-taking within safe limits and enables them to exercise a considerable degree of self-determination as they design, not only the future classroom, but also the future school.

In summary, the main objective of the iTEC was to help to bring change to schools across Europe, by means of piloting innovative future classroom scenarios. Section 6.2 describes the directions of the iTEC project. Technology was regarded as an aid to help bringing that change. In that sense, the Composer was conceived as a web application, where teachers are able to publish innovative learning activities and learning stories—following a kind of wiki-like philosophy (Sect. 6.3). The Widget Store was aimed at providing a central repository of embeddable widgets, which teachers may use as a type of building blocks when posting their lessons online, for instance, in Learning Management Systems (Sect. 6.4). The People and Events (P&E) Directory was conceived as an online place, where teachers may look for experts in a certain area of knowledge and also find events that may have an educational value, such as webinars that are suitable as an aid to teach something (Sect. 6.5). Finally in Sect. 6.6, the User Management and Access Control (UMAC) is the "glue" that ties together all those applications. The chapter is finalized by conclusion in Sect. 6.7.

6.2 Eduteka—Teacher as a Connected Learning Designer

The iTEC project, through its work with major ICT providers, European Ministries of Education, and leading education research institutions, created a collection of tools and resources, shown to improve learning and teaching through more than 2,000 classroom pilots.

A model has been established for incrementally, but fundamentally, bringing about change in classroom practice, in order to better prepare young people for the challenges of society and the workplace. It is based upon the increasing use of inspiring and innovative Learning Activities, involving advanced pedagogical approaches, supported by effective use of the ICT.

The creation of these Learning Activities is based upon innovative visions of the future classroom, called Future Classroom Scenarios, keeping pace with trends in society and technology. The tools provided to create the scenarios and Learning Activities are packaged as a "toolkit" named Eduvista+. This toolkit is provided together with an open programme of training, to support wide scale adoption at different levels across European education systems.

The original design of the toolkit involved three parallel and integrated streams of work. This originally resulted in the delivery of three separate but complimentary toolkits:

- Eduvista—The Future Classroom Scenario Toolkit.
- Edukata—The Toolkit for Designing Innovative Learning Activities.
- Eduteka—Technologies for Advanced Learning Activity Design.

In the final stages of the project, three separate toolkits were further integrated to provide a single toolkit, Eduvista+. Within Eduvista+, the technical components previously within the Eduteka toolkit are presented alongside the pedagogical design processes. This is intended to emphasise the role of technology to support innovation in lesson design, placing pedagogical considerations first and foremost.

Following a central principle in the iTEC, that the technology is there to support change and not drive (or somehow force) change, each of the iTEC technical outputs has been developed specifically not to be "disruptive". Instead, they are designed to enable teachers to adapt to and exploit the technology rich society they live in, but which does not sufficiently make its way into the classroom. Another principle within the iTEC was the emphasis on the teacher as a "designer" and that the design process must be "collaborative". For many countries, this represents a deep cultural change in the role of the teacher by emphasising the importance of creativity, and diminishing the view that the role of a teacher is an isolated one.

The Composer tool helps teachers to find Learning Activities, based on a taxonomy of transversal (21st century) skills. The Composer also allows teachers to create and adapt Learning Activities and share them within their community. This has so far resulted in a growing collection of inspirational materials. A valuable feature of the Composer tool is the facility to help teachers find and make use of new technologies and resources. Teachers are able to select a Learning Activity, and are then provided with suggested technologies, which may be appropriate to use in the delivery. This is a powerful way of exposing teachers to new technologies and, as a consequence of that, new approaches to learning and teaching e.g., teachers, who may not have considered using online chat or collaboration systems, will discover a number of technologies, which enable this and which could be free and easy to use. This will give them new and engaging approaches to formative assessment and classroom management, for example. The technology also provides "intelligent" advice on resources through the Scenario Development Environment (SDE), which has the capability to make informed recommendations, based on the teacher's local context. Recommendations can, therefore, be personalised for each user.

The Composer and the SDE are also designed to provide resource recommendations from a repository of learning tools called widgets in the Widget Store. These widgets are commonly simple tools and support a range of classroom activities. They may be something as basic as a calculator or note pad, or something more sophisticated like the award winning, the iTEC TeamUp tool, used to support collaboration and reflection.

The Widget Store can be an integrated component of the Composer, but can also be used as an independent tool, allowing teachers to search the store themselves and find popular widgets (frequently downloaded or recommended by other users). Teachers are also able to create their own widgets without need of technical knowledge. They can create their own widget collections by “capturing” parts of the internet, such as videos, animations and online activities, and collect them together in one place. The Widget Store has been designed to be integrated into a number of common educational platforms e.g., Moodle, DotLRN, Active Inspire, SMART Notebook, and several others. As a consequence of this, teachers have the potential to access the store in an environment they are familiar with, rather than having to find and register in a multitude of unfamiliar (often challenging) environments and platforms. The ability to access these resources and tools so easily, is intended to allow teachers to quickly discover and adopt new technologies in support of innovative and advanced pedagogy.

Another technological output from the iTEC is the People and Events Directory. This tool supports teacher community development by connecting teachers with similar interests, allowing them to share knowledge and experiences and facilitating professional network development and collaboration.

The nature of technical innovation in the project is essentially one of making new connections. Each of these tools helps to reframe the role of a teacher as a designer, and to emphasise the importance of collaborative design and openness in sharing ideas and resources. They are designed to provide simple but powerful features, which steer teachers towards greater adoption of pedagogical approaches that involve 21st century Skills, and make use of new and unfamiliar technologies, and new ideas and contacts.

6.3 Composing Learning Activities

In order to create efficient and effective learning environments—not only open and configurable ones—the concept of the iTEC Composer also plays a central role. The iTEC Composer constitutes a unique authoring tool that supports the composition of learning stories that are enriched by resources made available via the iTEC Application Store and the iTEC Back-end Registry. The learning stories created can be re-used for a semi-automatic customization of a shell in order to support learners in achieving their educational objectives.

Technically speaking, the iTEC Composer allows for the registration of learning stories and Learning Activity and Resource Guides (LARGs) as well as technical settings. It also functions as a back-end tool for performing administrative tasks upon the iTEC Registries such as the iTEC Application Store, the iTEC Back-end Registry, and the iTEC Content Repositories. The iTEC Composer provides functionalities for registering resources such as applications, content, devices, events, as well as persons and for bundling them in the context of learning stories.

The iTEC Composer will, for example, be used by the ICT Coordinators (and potentially more stakeholders like publishers and teachers) for the registration of resources as well as including a complete definition of technical settings. The tool allows users to execute Create, Read, Update, Delete (CRUD) operations on the iTEC Registries for the iTEC Resources. From the technical point of view, the User Interface (UI) of the iTEC Composer is realized by following a widget-based approach.

Section 6.3.1 provides Composing Learning Activities and Learning Stories. Managing resources are represented in Sect. 6.3.2. The context of the iTEC Scenario Development Environment is discussed in Sect. 6.3.3.

6.3.1 Composing Learning Activities and Learning Stories

For authoring a learning activity, the iTEC Composer provides an intuitive user interface providing the elements. As shown in Fig. 6.1, beside basic fields like title and description, the author of the learning activity can express, why a teacher would want to adopt the learning activity ("You can look forward to …"). In addition to that, learning outcomes can be expressed in a simple, prosaic manner ("Your students may learn …"). Moreover, there is a "technology section" that allows the author to express ideas for using technology within this learning activity in the form of a narrative.

The teacher also has the possibility to directly select functionality or a concrete the iTEC resource to become part of the learning activity using an intuitive drag and drop interface. The resources include content, applications, experts, and events, which are registered in the "Manage" Section of the iTEC Composer.

A learning story merely consists of one or more learning activities. Consequently, for authoring a learning story, the iTEC Composer provides a user interface, that allows for selecting suitable learning activities of interest out of a pool of learning activities, which had already been registered.

In general, the iTEC Composer implements a wiki-style approach. That is, all resources and elements within the iTEC Composer are by default considered to be public and hence may also be edited by other users. While this is still considered to be a valid concept. Besides, each user of the iTEC Composer tool is provided with a dedicated personal space, that allows a user to collect learning stories and activities, which are of special interest for him/her.

A teacher can easily copy a learning story of him/her choice to him/her personal space by clicking the button "Copy to my learning stories".

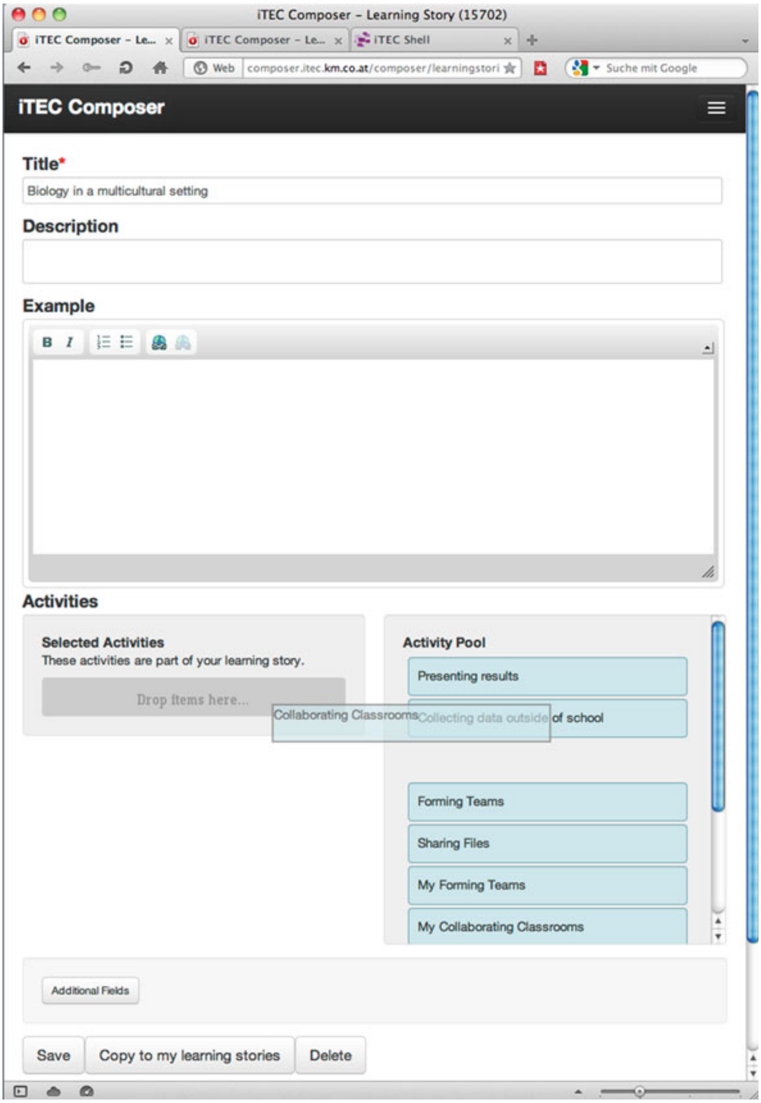

Fig. 6.1 Screenshot of the composer UI for registering a learning story

6.3.2 *Managing Resources*

A teacher may use the iTEC Composer to register and manage the iTEC Resources. Therefore, the Composer provides an intuitive user interface for registering applications, content, events, and devices.

Registering content supports the registration of any kind of digital assets such as hand-outs or work sheets as commonly used by teachers in primary and secondary school. Alternatively, full-fledged content packages in standard formats such as IMS Content Packaging [1], SCORM [2] or Common Cartridge [3] can be uploaded as well. The Learning Object Metadata (LOM) can be added in order to describe the digital resource from an educational perspective.

Registering applications works in a similar way. However, instead of uploading content a widget can be added. Applications are described using a functionality classification. The functionality classification differentiates between various educationally relevant technology-supported activities such as online annotation, asynchronous discussions, or drawing and painting.

Devices can be registered with the iTEC Composer. Again annotations with respect to supported educational activities are possible.

The ITEC Composer also supports the registration of events. Events can be described with standard data elements such as name, description, date, and duration. A subject classification supports the categorization according to educational needs.

6.3.3 Discovering the Most Suitable Educational Resources: The SDE

When creating a learning activity in the Composer, teachers have to select educational resources. This may be a challenging task for most teachers in primary and secondary education due to an excess of offer. The iTEC project has among its purposes to help teachers in more easily discovering, assembling, and fully exploiting educational resources beyond content, e.g., tools, educational events, experts. This is the context of the iTEC Scenario Development Environment (SDE), a software application aimed at offering supporting services in the form of suggestions or recommendations oriented to assist teachers in their decision-making when selecting the most appropriate elements to deploy learning activities in a particular school. The SDE is based on an ontology that was developed in a collaborative way by a multidisciplinary team of experts. Its data set is fed not only from entries that come from registrations made by human users—using tools from the so called the iTEC Cloud—but also from software agents that perform web knowledge extraction, that is, automatic enrichment of the semantic data with additional information that come from web sources, which are external to the project. The SDE defines an API that allows for the Composer to integrate its functionalities (Fig. 6.2).

Recommendations. In the iTEC, a series of directories, in which the user can register technologies, and also events and experts, were developed. Thus, the Composer includes a directory for hardware and software technologies; the People and Events Directory, as its name hints, enables to register educational events as

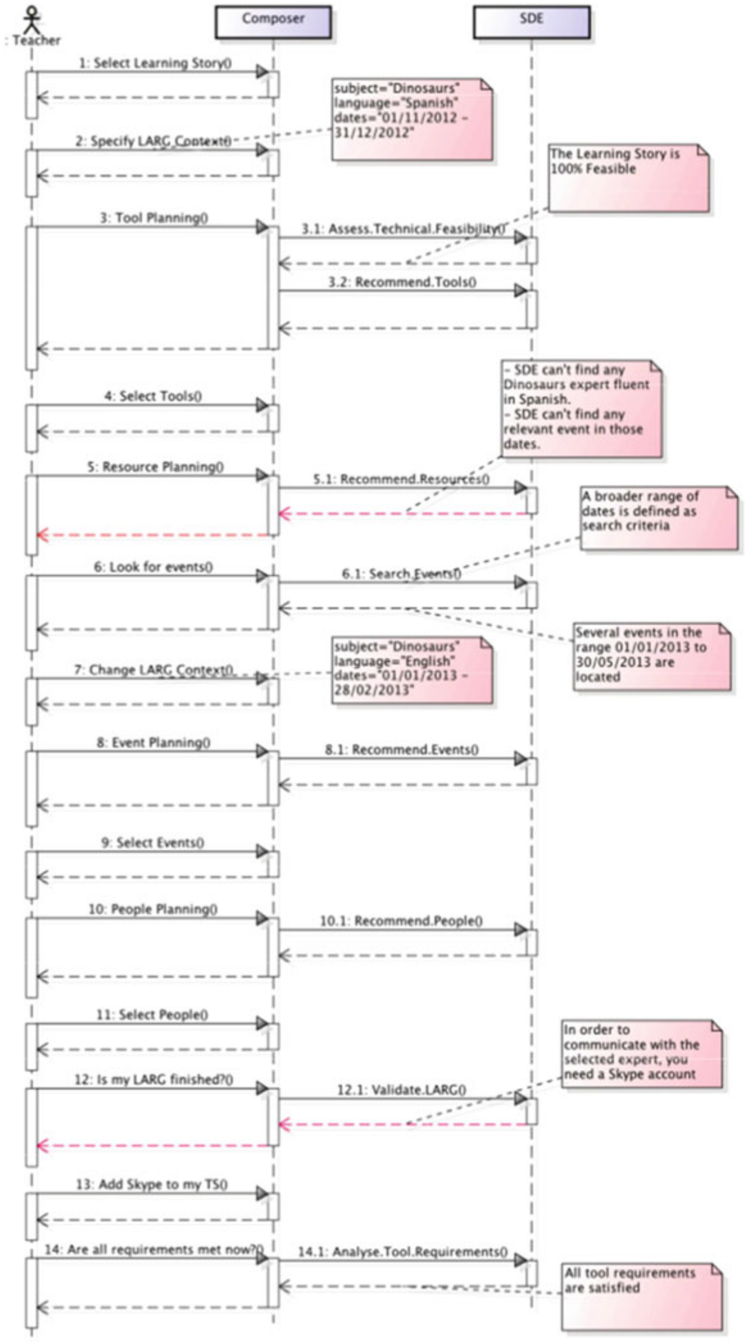

Fig. 6.2 Relationship of the SDE with the Composer

well as experts in some knowledge areas; and the Widget Store is a repository of widgets ready to be used in the educational practice.

The iTEC project proposes the SDE for the task of selecting technologies, events, and experts among a huge number of alternatives. Thus, the SDE was devised as an artificial agent that follows an semantic approach to generating recommendations. A teacher, when planifying a learning activity, may thus use the SDE for getting suggestions of interesting resources that he/she can use. The identification of factors that might impact the relevance of resources, as well as the definition of their associated weights, was made by following a rigorous methodology initially proposed in [4], which involved the participation of experts in several Control Board iterations.

Enrichment. The task of registering technologies, events, and experts in a series of centralised directories suffers from two main problems: the first one is the registering task itself, which entails a certain cost because it is a time-consuming task; and the second one is to do it correctly, that is to say, that the metadata of technologies, events, and experts be accurate enough. In order to solve those problems, the artificial intelligence agent uses a strategy based on web knowledge extraction; that is, it crawls the web and gets information about technologies, events, and experts that were not registered yet; and it also crawls the Web to get more information about metadata of technologies, events, and expert that were already registered. Even though web knowledge extraction processes were not initially considered in the iTEC's Description of Work, we decided to incorporate these techniques to the SDE—continuing the line of previous research work in the field of semantic enrichment of knowledge bases [5].

6.4 The Widget Store

The iTEC project plan set out to make the components required by the teaching scenarios (people, tools, services, and content) interoperable and discoverable, so that teachers could more easily select and combine relevant components. This raised very substantial practical challenges. Teachers across Europe work within very different organisational structures with different learning management systems (or none at all), and widely different policies on teacher access to systems and learner access to the Internet. An infrastructure was required, which would enable services to be managed and deployed across this range of contexts, and which would provide interoperability based on open specifications. The W3C Widget specification [6] was identified as a means of achieving this. Users can embed a W3C widget in a container, typically a Web page, but the functionality provided by the widget is not provided by the server, which is responsible for delivering the container. Rather, a dedicated server provides the functionality, and delivers it across the range of contexts within, which the widget is deployed.

The main idea behind this approach is that teachers may select in the Composer the widgets that they find more interesting when creating learning activities—being assisted by the SDE in the process of discovering widgets.

This approach enabled the iTEC to address its requirements by making use of an emerging technology, which was addressing the needs of the Internet as a whole, rather than developing a specific solution for the project or one aimed primarily at the education sector. At the time, when this decision was made, there were signs that the W3C widgets would become a widely adopted in the mobile area, for example, by Windows Mobile [7] and Opera [8], enabling the iTEC to make use of an extensive ecosystem of the W3C widgets. In practice, however, the W3C widget specification has not gained widespread adoption. Nevertheless, the specification remains valuable as a means of delivering services across the iTEC, and as the basis of the iTEC Widget Store.

In implementing the infrastructure for the W3C Widgets, the iTEC project built on the Wookie Widget Server. This is a reference implementation, if the specification, established by the TENCompetence project, which developed it as a means of delivering services to Units of Learning created with the IMS Learning Design [9]. Many of the technical services used in education require individual users to be identified, for example, in chats, voting, or collaborative texts. The W3C Widget specification does not support any identity management functionality, and so the iTEC project worked extensively on implementing an API for Wookie that enables widgets to make use of contextual information, such as information about the user, and the context, in which the widget is being used [10]. The Wookie server was accepted by the Apache Foundation Incubator, and in 2012 graduated to become a Top Level Project.

To facilitate integration of widgets into Web pages, plug-ins were developed for target platforms, including the principle Virtual Learning Environments used in the iTEC: Moodle and .LRN. In this way, when a user is creating a page in a course, a Wookie object can be included. The user can then configure this by using the interface provided to select a widget from a remote Wookie server. Within the iTEC, Wookie is used to deliver information from the people and events directory, the iTEC tools such as TeamUp, and widgets created by members of the project team, teachers, and learners. This proved to be an effective means of delivering tools and services across multiple systems, with the principle constraint being the restrictive policy of some institutions, which choose to block access to any Web page combining services from multiple sources.

When choosing a widget, users selected the one they wanted from a page generated by Wookie. However, as more the iTEC widgets were created, it became difficult for users to identify the most appropriate one to use. The Widget Store was designed and developed by the iTEC to meet that need (for example, see the user stories provided in [11], pp. 22–28), enabling users to search for their favourite widgets (and those of others), to tag them, and to organise and describe them according to the iTEC catogories. The iTEC Widget Store is a client having access to a service, which manages the data for tags, functionalities, reviews, and ratings (Fig. 6.3). This service is based upon an open-source web application called

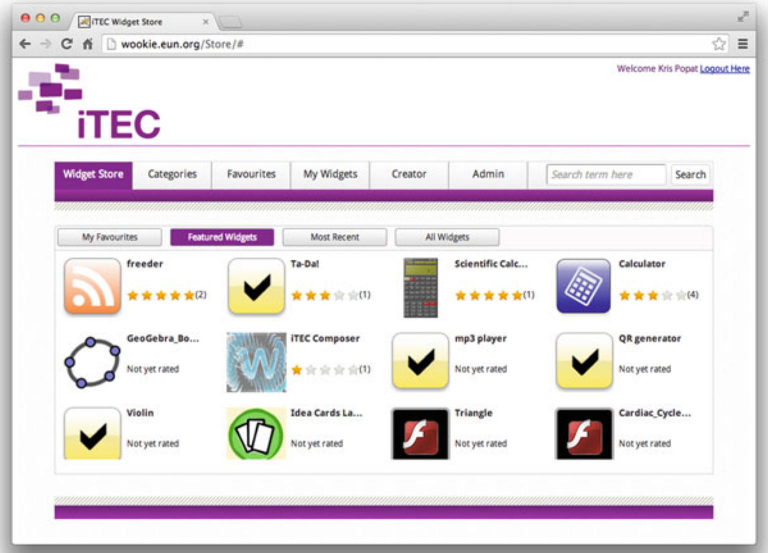

Fig. 6.3 The iTEC Widget Store

Edukapp [12], initially funded by the Joint Information Systems Committee (JISC) in the UK, but which has since been developed by the iTEC, with additional input from the ROLE project [13]. The Widget Store has been through a number of iterations following feedback from users, and the store front of the final major release made by the iTEC (release 1.4). The Widget Store exposes an API, which provides information about the widgets it contains and their descriptions enabling the other components of the Eduteka to identify widgets, which are potentially valuable for settings and users.

As mentioned above, the W3C Widget specification has not spawned an extensive ecosystem of widget based applications. As a result, it has been essential for the iTEC Widget Store to provide the means, whereby users can create their own widgets, and the Widget Store provides four mechanisms to this end:

1. *Embed codes*. The user can find an embed code on the Web (for example, a YouTube video or a presentation from Slideshare, and a W3C package is automatically created to show this content).
2. *Upload a set of Web pages*. The user can upload a zip file with a set of linked Web pages. These are then automatically packaged as a widget and served by Wookie.
3. *Upload a Flash file*. These are automatically packaged and served as widgets.
4. *Upload a W3C Widget*. These are parsed and deployed by the server.

This provides a route into widget creation for users with very limited technical knowledge, while also supporting the creation of sophisticated functionality developed in JavaScript, and optionally making use of the Wookie API. Administrators can enable a publication workflow, which requires all widgets to be approved before they are made publically available. The provision of widget creation capability was intended to provide a way of creating a sufficient number of useful widgets, but in practice it has also changed the nature of the Widget Store. The majority of the widgets stored on the server are now content, which has been captured from the Web, and wrapped by the store as a Widget [14]. The result is that the iTEC Widget Store is not only a solution to the technical problem of delivering services across multiple platforms and contexts, it is also a means whereby learners, teachers, and coordinators can capture, describe, and deliver functionality and resources from the Web, a process which we describe as curation [15]. This enables an individual teacher or pedagogic coordinator to gather and describe a set of resources for a particular curricular and pedagogic context. Resources can deploy in any course and they are called upon to teach. It seems likely that this will be particularly valuable for pedagogic coordinators, who can validate particular resources for particular pedagogic purposes, and share these with their peers or client group.

The iTEC Widget Store has been implemented as a widget, and its full functionality can be accessed when integrated with the identity management of a container application or via anonymous access from any web page. The Open Mashup Description Language, developed by the Omelette project, has been included as a course format in the Moodle integration to support the import and export of collections of widgets.

6.5 Resources Beyond Content: The P&E Directory

As part of its comprehensive approach to the change management, when introducing the ICT in schools, the iTEC investigates how learning can be made more engaging by providing non-traditional resources through the use of the ICT. While, the ambient intelligent vision from 2001 [16] was unrealistic, it was indicative of a shift to different forms of more learner-centred, the ICT-facilitated approaches including personal learning, individual learning, self-regulated learning, and ambient schooling [17].

Therefore, the iTEC explores to what extent interactions other than the traditional classroom interactions can possibly enhance engagement. More in particular, the iTEC makes information about Persons and Events available that can contribute to such interactions. By doing so, the iTEC seeks to facilitate the exploration of the ICT enabled new scenarios, new roles, and situations in the learning process.

An illustrative user story is as follows. Belgium has two astronauts that have visited the International Space Station (ISS). The latest, Frank De Winne, remained 6 months in space and was commander of ISS expedition 21. The MoE of Flanders, keen on raising interest in science, has asked him to register as an expert in the Persons and Events (P&E) directory of the iTEC. Mr De Winne accepted with pleasure and he agrees to be available for six chat sessions with students and their teacher. The MoE sets up six chat events and registers them in the P&E directory. A few days later Chris a science teacher is reading the iTEC scenario "Beam in the expert". She considers this an interesting scenario and consults the P&E directory, easily identifying experts that speak Dutch and have expertise in science. She identifies Mr. De Winne and selects one of the six chat sessions that he is offering. The pupils prepare very well and during the chat session interesting questions arise such as about the smell in the ISS, if you don't have fresh air for 6 months…

As the example illustrates, different stakeholders in the learning process can benefit from sharing persons and events:

- Learners can more easily get help from experts, coaches, and co-learners.
- Teachers can more easily get access to persons that want to contribute to the learning activity such as experts, coaches, other teachers. They get also more easy access to what other teachers or institutions are organising as events that are interesting for education.
- Persons traditionally not involved in the learning activity can now more easily express their willingness to participate. It is, for example, known that a number of people associated with musea, cultural institutions, and even business are willing to do this.

A short description of the Persons and Events Directory one can find in Sect. 6.5.1. Section 6.5.2 provides information about federal architecture.

6.5.1 Directory

The Persons and Events Directory allows registered users to find other persons that can contribute to a learning activity and to find events that are of interest to a teacher or students in their learning activity. While professional social networks exist, such as LinkedIn, are inadequate for our purpose; i.e. to find people in European multilingual private network based on country, language(s) they master, country, subject, and ways to contact them. The faceted search for a person is illustrated in Fig. 6.4 (for privacy reasons some data are fictitious). Here the search is effectuated using a number of filters shown on the left. The data available for the person are shown on the right.

Similarly, Events from across Europe can be found based on country, language, subject, event category, and event place. The search is depicted in Fig. 6.5. These events may come from different sources (see next section) and be of different types. Through the use of multilingual vocabularies, users can see most of the data in their own language, while they need to be entered only once.

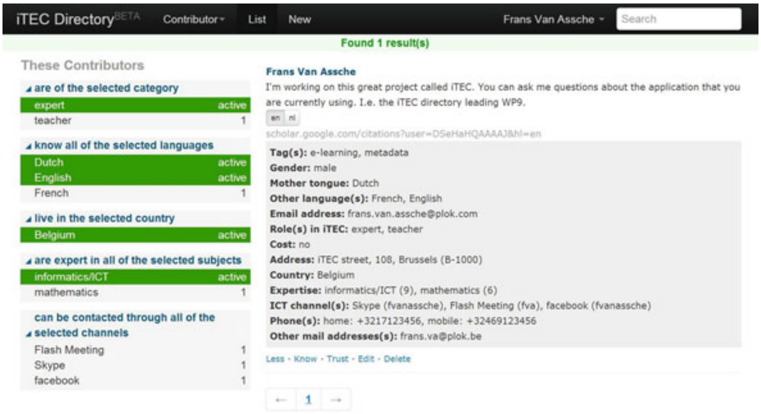

Fig. 6.4 Finding persons

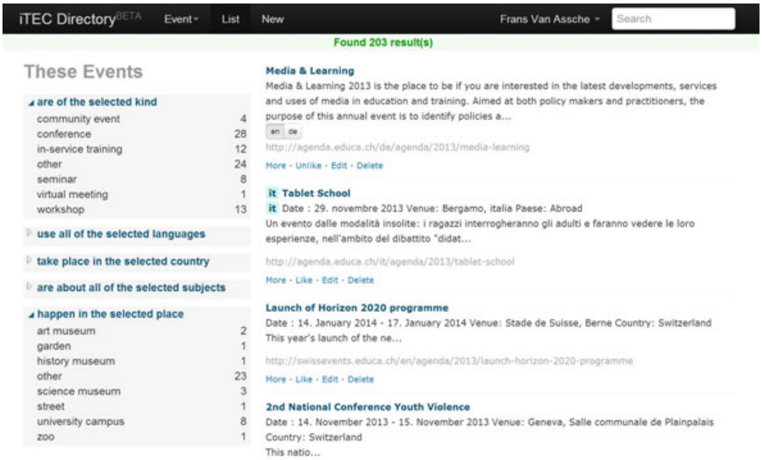

Fig. 6.5 Finding events

6.5.2 *Federated Architecture*

The Persons and Events directory has a federated architecture. As such the directory obtains its data from different sources depicted at the right of Fig. 6.6. The Persons and Events directory reads the RSS channels from existing educational repositories such as from Ministries of education, European portals, etc. Examples are the RSS channels from the Swiss Education Server Educa in different languages, KlasCement in Flanders, INDIRE in Italy, ERTE DGE (MoE) in Portugal, Oktatas (MoE) in Hungary, CNN news for students, interesting events in Budapest, Manchester Metropolitan University, etc.

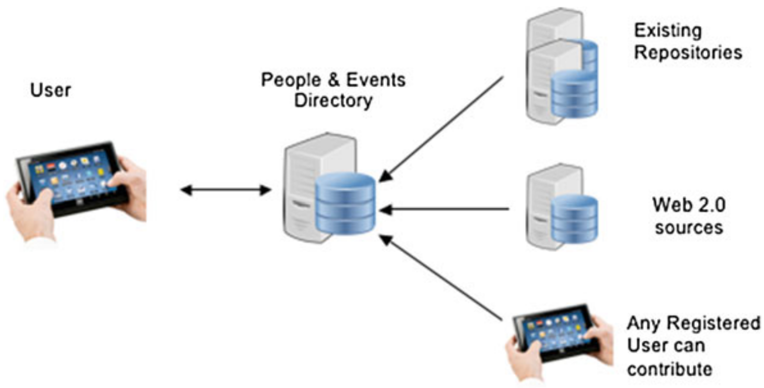

Fig. 6.6 The federated architecture of the Persons and Events Directory

In addition, the Persons and Events directory is harvesting from other repositories such as the SDE repository which scrapes existing web sites, transforms it into web 2.0 data structures and exposes it in either RDF triples or JSON data structures. As an example events are scraped from CEN/ISSS, the open education portal, etc. Finally, registered users can submit new entries to the Persons and Events directory.

6.6 Tying It All Together: The UMAC

The iTEC integrates a wide variety of components: shells, web applications, self-contained widgets, widget-based applications… This integration raises some questions in terms of user management and access control:

- User authentication may take place at the shell level, but also some integrated services may require some form of authentication or at least be aware of the visiting user's identity. This implies the need for an authentication mechanism that can span the range of components and provide a consistent information about the user.
- Access control policies may be defined centrally, at the iTEC Cloud level, but these policies have to co-exist and be consistent with those defined at the shell level, or at the integrated services level, if any. Again, this requires an authorization mechanism that integrates at the various levels of the architecture.

Our goal was thus to design a system that would meet the following requirements: allow user authentication at the shell level and pass the information into sub-components (widgets and back-end services); allow access policies to be defined globally to the iTEC Cloud, based on a Role-Based Access Control model, and have those policies propagated to the sub-components; from the global access rules, provision local policies at the level of the iTEC back-end services; designed solution should support interoperability with major service providers.

Let us consider some technical aspects such as proposed solution (Sect. 6.6.1), the UMAC server (Sect. 6.6.2), the UMAC filter (Sect. 6.6.3), and the UMAC library (Sect. 6.6.4).

6.6.1 Proposed Solution

The interoperability requirements led us to focus on open standards and protocols to build authentication and authorization mechanisms. We performed a thorough study, and identified candidate protocols like SAMLv2 [18], OpenID [19], and oAuth [20]. Due to their technological maturity, their relative simplicity, their support for web interactions, the availability of libraries and their wide adoption by main actors on the net, we selected oAuthv2 and OpenIDv2 as the basis for our solution. The fact that users are warned, when an application wants to access protected data, was also an element of choice.

To integrate those protocols into the iTEC environment, we designed the User Management and Access Control (UMAC) framework, which comprises the following components:

- The UMAC server is responsible for user authentication, issuance of tokens, and management of user data and privileges; it plays the role of the OpenID's Identity Provider, the oAuth's authorization server, and implements a back-end service to access, store and manage user data and privilege information.
- The UMAC filter is an authorization guard that sits in front of back-end services; the back-end service represents the oAuth's Resource Server, and the UMAC filter is in charge of validating access tokens.
- The UMAC widgets are a collection of widgets that allow to access and manage authentication and authorization information in the iTEC Cloud. Those widgets allow registering a new user, to update a user's details, to create sets of users, and to assign the iTEC roles.
- The UMAC library is a JavaScript library of tools to help the widget developer to easily integrate with the UMAC framework and not care about the various protocols' implementation.

6.6.2 The UMAC Server

The UMAC Server serves two main purposes: authenticating users and controlling access to back-end services.

To authenticate users, the UMAC Server implements the OpenID Provider specification. It handles authentication requests from the iTEC relying parties, typically shells or web applications, authenticates users, and responds to relying parties. The UMAC Server supports SREGv1.0 and AXv1.0 OpenID extensions to provide basic information of logged in user (username, first and last names, email address, language, timezone, country). Authentication is checked against a local database of users.

One of the requirements drawn from a survey we ran among participating teachers, mandates that the iTEC should allow users to login using third-party credentials, namely Google, Facebook, or Yahoo. Thus the UMAC Server supports user authentication using any of those systems, by implementing an OpenID Relying Party (in the case of Google and Yahoo) and an oAuth client (in the case of Facebook).

Access control to the iTEC services is handled by the UMAC Server. Access requests may come from widgets or web applications. In addition to the authentication and authorization functionalities, the UMAC server is also used to store user information. Finally, the UMAC server is used to manage user privileges; those privileges span all the iTEC services, i.e. apply equally to shells, widgets or back-end services.

For a seamless user experience, the UMAC authentication is propagated to the shell through a plugin mechanism, which is dependent on the shell itself. In this way, once the user is authenticated, all shell components (typically widgets) can reuse the user information.

6.6.3 The UMAC Filter

The UMAC filter is designed to be put in front of back-end services, and interacts with the UMAC server following the oAuthv2 protocol to control access to the services by ensuring that only authorized requests get served. The current implementation of the filter takes the form of a servlet filter, which makes it very easy to integrate and (de)activate and realizes a separation of concerns by allowing the service developer to work independently from the access control mechanism.

6.6.4 The UMAC Library

The UMAC library is a Javascript library of functions that aims at facilitating the development of widgets and their integration with the UMAC authentication service, more precisely, the oAuth authentication endpoint's service. It hides the complexity of the protocol by providing methods to manage the whole authentication process (request for token, redirect to authentication form, token transfer to requesting component and error handling).

Figure 6.7 presents the UMAC components (in yellow) as well as the interactions with other iTEC systems. The UMAC Server is used for authentication (solid lines) either from shell, widgets or web applications like the composer. This follows

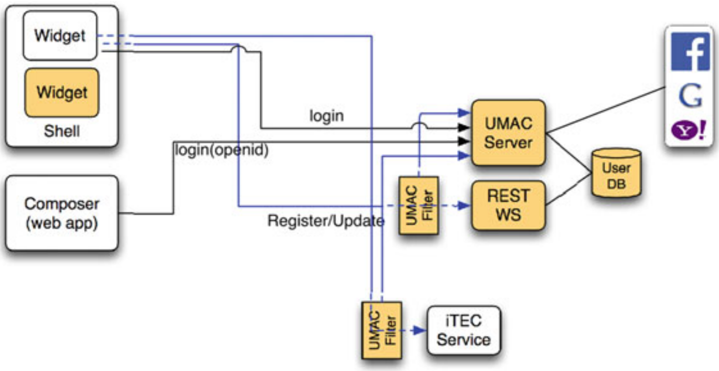

Fig. 6.7 The UMAC components and interactions

the OpenID protocol. Authentication may be local (using the User DB) or rely on third-party authenticators (right-most box). Regarding authorisation (dashed lines), UMAC widgets allow to register or update user information through the UMAC REST Web Service, which is protected by the UMAC filter. Similarly, any other the iTEC component may access iTEC back-end services, which are protected by the UMAC filter (see bottom of the diagram).

6.7 Conclusions

This chapter has explained how the ICT can be used during the process of designing learning activities, in line with the new pedagogical approaches that have been developed in the context of the iTEC project. Thus, we have explained how the Composer can be used for creating learning activities. These activities may integrate educational resources, which teachers can discover with the help of recommendations from the SDE. Educational resources may be of type widget, which are maintained by the Widget Store; but they can also be non-traditional resources such as experts in certain areas of knowledge as well as events that may have an educational value—which are stored in the People and Events directory. Finally, the "glue" that ties this infrastructure together is the UMAC, which provides a single sign on mechanism.

These technologies have been piloted in more than 2,000 classrooms, in several cycles all around Europe. Even though they are experimental technologies, still in their way to attaining enough technological maturity, results have been quite positive. As final conclusions we can highlight the following ones.

The wiki-like approach of having a central repository of learning activities, where teachers can contribute new activities and discover those created by others, is a factor that fosters motivation and innovation. Recommendations of educational resources are useful, because they perform an automatic pre-selection of the most suitable educational resources—and this is very necessary nowadays, as the offer of educational resources is reaching epic dimensions. Non-traditional resources, such as experts and events, may enrich the traditional way of teaching and learning. A central directory for people and events is a promising technology that is bound to play a key role in the future, enabling social interchange among teachers and other stakeholders, and promoting events that may have an educational value. Widgets are a smart way of encapsulating applications, in such a way that they are interoperable between different Learning Management Systems.

In a project with such a big size, with several research groups working in parallel, integration is always an important challenge. In the iTEC, the authentication server has played a key role for integrating all the different components.

In summary, the iTEC has shown that technology can be successfully leveraged in teaching/learning processes in the classroom, provided that an adequate pedagogy is being used. The main next step is to mainstream the iTEC approach, that is to say, going beyond pilot experiences and making a definite impact in correct teaching/learning practices in European schools.

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Chapter 7
3D Virtual Worlds as a Fusion of Immersing, Visualizing, Recording, and Replaying Technologies

Mikhail Fominykh, Andrey Smorkalov, Mikhail Morozov and Ekaterina Prasolova-Førland

Abstract This chapter discusses 3D virtual worlds as a fusion of technologies for serious applications. A variety of new trends in the area and original findings are discussed and exemplified with methods and features designed. The goal of this chapter is to evaluate and envisage, what benefits can be acquired if such trends and features are fused under a single platform. Specific trends considered in this chapter include increased sense of immersion with virtual reality devices, simplification of control with joysticks, and mobile devices, working with large amounts of multimedia content, and capturing activities using virtual recording. The discussion is supported with the literature review and evaluation of the features developed for vAcademia virtual world. A particular focus of the chapter is on the discussion of how the new properties of 3D virtual worlds can increase their efficiency for serious applications, enable new scenarios of use, and improve user experience.

Keywords 3D virtual worlds · Technology · Collaboration · Motion capture · Head-Mounted displays · Natural navigation · Virtual recording · vAcademia

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7.1 Introduction

The great potential of 3D Virtual Worlds (3D VWs) for collaboration and other serious applications such as education, healthcare, military, and business have been investigated and reported [1–6]. Most of these applications are considered to exploit advantages of 3D VWs such as low cost and high safety, 3D representation of users and objects, and interaction in simulated contexts with a sense of presence. At the same time, this technology has certain limitations that led to a number of challenges for applying it in various domains.

One of the most serious challenges in adapting 3D VWs for serious applications is the lack of features that professionals use in their everyday work [7]. Such applications often involve cooperation and co-construction, which need to be supported and often requires tools that do not exist in most 3D VWs [8].

Advanced human-computer interfaces can increase the value and transferability of virtual experience as human mind is closely connected to the sensory-motor experience [9]. The theory of Embodied Cognition suggests and stipulates that human mind is defined by the body and specific context [10]. Therefore, embodied experience of activities in 3D VW is closer to the real-world experience. This makes involvement of the body in the process of interaction with 3D VW important.

In addition to 3D VWs, various other Virtual Reality (VR) technologies that involve human body in the interaction are being developed or adapted for serious applications. However, the cost is becoming a limiting factor in most cases. Industry, military, and healthcare are named as the only areas, where these technologies are starting to be used [11, 12]. Thus, the development of low-cost solutions using off-the-shelf components is necessary.

This chapter describes an original approach that addresses the challenges mentioned above. This approach is based on a fusion of several technological solutions, schemes, and devices in a single system. Three particular components suggested for fusion fall in the following topics: natural navigation with high level of immersion, displaying large amount of meaningful media content, and virtual recording and replay. The main application domain of the fusion of technologies proposed in the chapter is collaboration. Section 7.2 of the chapter contains an overview of literature for each of the topics. Section 7.3 provides an original design of several features in each of the topics. Section 7.4 presents an attempt to fuse the features with the goal of improved user experience or enabling new use cases and applications. Section 7.5 provides an example of such new scenarios. Section 7.6 concludes the chapter, outlining the directions for future work.

7.2 Background

The literature review includes three issues: immersion and tracking technologies (Sect. 7.2.1), media content in 3D Virtual Worlds (Sect. 7.2.2), and 3D virtual recording and replaying (Sect. 7.2.3).

7.2.1 Immersion and Tracking Technologies

Modern 3D VWs are usually built on a type of VR technology—a desktop VR, as this facilitates access on a standard desktop computer. In the past, 3D VWs have been built on various technologies and accessed through different interfaces [13]. Another type of the VR technology that is used in 3D VW can be called immersive VR, as it goes beyond desktop and extends audio-visual experience with more natural navigation and control, thus increasing the sense of presence and immersion [14].

Various VR systems have a number of unique features and applications. The major change in the development of the VR in the recent years is the appearance of affordable devices. Therefore, their application area is becoming much wider. A number of studies have been done in this area outlining advantages and limitations of these technologies, for example, as working and training environments [15, 16]. The main arguments for its use are that 3D environments are engaging as media, and that the use of 3D rather than 2D media facilitates comprehension, exploiting the natural capabilities of humans to interact in 3D space [17–19].

Relatively few simulations have been built for immersive VR, though the evidence of use in very high-value training (vehicle simulation such as aircraft simulators or military training) is compelling [20]. There have been extensive studies of the impact of 3D immersive visualization on user behavior, lower-level task performance, and comprehension of data. A key characteristic, arguably the one that motivates the use of immersive VR in high-value training, is that participants tend to react as, if the scene they were seeing was real. That is they behave in a way that is similar to their behavior in a comparable real situation [21].

This behavioral response itself distinguishes an immersive VR from other media, even desktop VR, as when immersed the participant can actually act, to a limited extent, in the same way they would in the real world (e.g., by moving away from a threat). In desktop VR or other media, this capability is severely limited by the form and structure of the interface. There have been several studies of the relative capabilities of immersive VR and desktop VR systems on comprehension. Generally, the results indicate that for survey-like tasks a desktop VR may be preferred, but for interactive, exploratory tasks, immersive VR is preferred [22, 23]. However, these and other studies have not provided a complete requirement analysis that can predict tasks for which immersive VR environments are superior. This work is continuing with larger studies showing, what features of immersive VR are contributing to performance differences in certain tasks [24].

In the following, particular technologies are presented as a related work for this chapter.

Motion-Tracking. Low-cost motion-sensing technologies such as Microsoft Kinect, Nintendo Wii Remote, and Playstation Move provide researchers and practitioners with new opportunities for improving virtual experience. One of the first affordable motion-tracking devices was Microsoft Kinect. It is a low-cost motion sensing input device that is able to capture one or two humans [25]. The device consists of a video camera, a depth camera, and an Infra Red camera. Multiple examples of applications and systems built with motion tracking devices can be found. They include a low-cost alternative for interactive whiteboards and multi-touch teaching stations [26], automatic camera control system for presentations [27], anthropometric measurement system [28], and natural user interfaces in volume visualization [29].

Head-Mounted Displays. Head-Mounted Display (HMD) is a type of on-body VR devices that is worn on the head and has a display in front of the user's eyes [30]. Most of these devices consist of a display and a tracking system. It allows much greater immersion, as the user can control the direction of the view in 3D VW in exactly the same way as in the physical world—by turning the head. The displays of the HMDs have larger field of view and provide a stereoscopic image, making the experience more believable.

The Oculus Rift Development Kit 1 is an HMD device that has a 7-inch diagonal viewing area and 1,280–800 resolution split between both eyes, yielding 640–800 per eye [31]. The device has a three-axis gyroscope that senses angular velocity, three-axis magnetometer that senses magnetic fields, and three-axis accelerometer that senses accelerations, including gravitational ones [31]. A good field of view, stereoscopic vision, and fast tracking that are promised by the developers created huge expectations [32]. The HMDs are also used together with motion-tracking devices, improving the accuracy of tracking and the overall performance of VR systems [33].

7.2.2 Media Content in 3D Virtual Worlds

This section contains the necessary background on the topic of using large amount of graphical content in 3D VWs and related work.

Large Amount of Graphics in 2D Platforms. Nowadays, many examples can be found of large amounts of textual and graphical information that needs to be on the user's display at a time. This is often required in synchronous collaborative activities, when users have to be aware of what the others are doing. Such activities are typical for collaborative work. However, in practice software limitations do not allow implementing them to the full extent on either 2D web-conferencing platforms or in 3D VWs.

Modern web-conferencing platforms provide a shared workspace, means for content presentation, and various forms of interaction [34, 35]. However, it should be noted that in most cases, this technology is used for simple delivering of information (e.g., a presentation). Well-organized web conferences are often interactive (e.g., questions, comments, and discussion) and collaborative (e.g., mind-mapping, posting notes on slides, and using a shared workspace), but a single screen (with the content provided by the presenter) is used in most cases. The example of using breakout rooms illustrates synchronous collaborative activities in web-conferencing platforms, "allowing small groups to undertake tasks and bring outputs back to a plenary full group discussion" [36]. In this case, each group of users still works with a single shared workspace/screen, and the results are discussed one by one.

The implementation of such scenarios in 2D does not require large amounts of textual and graphical information on the user's display. The reason, however, is not in the lack of demand, but most likely in the technological limitations. When a collaborative scenario requires displaying multiple workspaces side by side, they can be located as tiles, but even with large monitors, this approach is rarely convenient. Alternatively, multiple workspaces can be set to different sizes (e.g., a moderator can enlarge them when required [37]).

Large Amount of Graphics in 3D Virtual Worlds. 3D VWs allow building environments that can accommodate multiple workspaces or virtual screens and convenient switching between different points of view (i.e. observing multiple screens or focusing on one). Natural 3D navigation or camera navigation and zoom can be used in such settings. This allows installing multiple virtual screens, for example, one with presentation slides, another with video or text notes. These affordances of the 3D space allow implementing active collaborative scenarios too, providing each user with personal virtual screen or several groups with screens.

However, in practice, existing 3D VWs allow using very limited numbers of virtual workspaces for collaboration on graphical content. For example, on some platforms, an environment may accommodate 2–5 virtual screens within the visibility area. This allows conducting several types of collaborative activities, including meetings and presentations. However, conducting activities that require active collaborative work with media content remain problematic. Another common practice is creating many screens with static images. This allows creating virtual galleries, which can be explored collaboratively and discussed by a group of people, but without active involvement in creating or modifying the content displayed. In such a way, the possibilities for conducting collaborative activities are also limited.

Many 3D VWs offer the "virtual screen" functionality. However, the features of such screens often have inferior implementation because of performance limitations related to the use of CPU for processing images. For example, 3D VW "Sametime 3D" built on OpenSimulator platform has a tool for working with sticky notes. However, the notes can only be placed on special square slots, their size is constant, and there is no possibility to use any other tools on the same screen (e.g., drawing). These limitations obstruct the effective use of the tool.

Technological Approaches to Processing Large Amounts of Graphics. Processing large amounts of images in 3D VW is mostly required when working on serious tasks such as collaborative work. In other tasks, displaying images, video or animation is also often required; however, the amount of content is smaller. Usually, an image is calculated on a CPU on the client side (e.g., in Second Life™ and Blue Mars™) or on the server side (e.g., in Open Wonderland™) and then loaded into the stream-processor memory as a texture.

Thus, the use of dynamic 2D images in existing 3D VWs is very limited. One of the most popular platforms—Second Life even has a hard limit of five dynamic images that can be rendered for one user at a time. This fact can be technically explained by the use of CPU for generating images. This technical limitation does not allow implementing some of the collaborative scenarios to their full potential.

Stream Processors. The Stream Processors (SPs) are specialized processors characterized by a very high data parallelism [38]. The SPs are most widely applied in graphics adapters, and therefore, their main tasks are related to processing 3D graphics such as a high-efficiency rasterization of polygons with texture mapping, fast affine transformations of the vertex data flow, interpolation of scalars, vectors and matrices on the surface of polygons, and calculation of lighting.

Due to the focus on the highly parallel computing tasks in 3D graphics, these devices have many hardware constraints [39, 40] and their cores have relatively simple architecture [41]. Therefore, most of the classical algorithms that can be executed on CPU cannot be executed on the SPs without modification.

7.2.3 3D Virtual Recording and Replaying

Capturing Virtual Activities. Capturing such activities is a complex task from the technological point of view as some part of the information is usually lost. Using other technologies, such as video recording of face-to-face activities or recording of web conferences is not as complex. However, recording using these methods changes the context of activities, they do not provide a possibility for collaborative work, or a method for further developing the 'crystallized activities' except for annotating them [42].

Currently, 3D VWs are also used for capturing activities but usually only as 'flat' 2D video, which eliminates many advantages of the technology such as sense of presence [43]. For example, this approach is used in Machinima—collaborative film making using screen capture in 3D VW and games [44].

Related Work on Virtual Recording. The demand for methods supporting asynchronous activities in 3D VWs and creating content out of synchronous activities was acknowledged as early as in the late 1990s, for example, by developers of CAVE and MASSIVE systems. MASSIVE-3 supported a mechanism called 'temporal links', which allowed "real-time virtual environments to be linked to recordings of prior virtual environments so that the two appear to be overlaid" [45]. The CAVE Research Network soft system had an application called Vmail which supported recording of an avatar's gestures and audio together with surrounding environment [46].

Another example is the system called Asynchronous Virtual Classroom (AVC). The developers were focused on solving the problem of time-sharing in distance learning. The AVC allowed users to watch a video image of a certain lecture and to control it, while software agents were playing some of the displayed participants and created a presence effect [47].

Later, N*Vector (Networked Virtual Environment Collaboration Trans-Oceanic Research) project was focused on developing a virtual reality technology for overcoming time-zone differences and time management problems. Within the project, there were developed three approaches to support annotations for asynchronous collaboration in virtual reality. These approaches included: VR-annotator—an annotation tool that allows collaborators to attach 3D VR recordings to objects; VR-mail—an email system built to work entirely in virtual reality; VR-vcr—a streaming recorder to record all transactions that occur in a collaborative session [48].

More recently, an Event Recorder feature was implemented (however, not developed further) within the Project Wonderland (later, Open Wonderland™). Event recorder implements the recording and playback of the 'events' caused by activities of users or agents. It is done in such a way that during playback a user is able to view the activities that those events caused. The "events" are recorded into an external form that can then be replayed to all the users in the world. The invention also includes a mechanism to record the current state of a VW to use it as the starting point to play back the recorded events.

A recovering feature is being developed for the new project by High Fidelity. Their new 3D VW is under alpha testing, but, the fact that a new and ambitious project implements such a feature demonstrates its potential utility for the modern community.

All mentioned projects were contributing towards developing technological solutions for capturing activities in 3D VWs or other similar environments. As presented above, creating content out of synchronous activities is an important in-demand task. However, there is a clear possibility for improvement, as the application potential was not yet realized.

7.3 Fusion Design of 3D Virtual World

This section presents the design of several features that enhance the technology of 3D VWs to improve user experience and enable new application domains. vAcademia has been used as a platform for research, implementation, and evaluation of new features and approaches to 3D VW design. Several main general-purpose design and development concepts of the vAcademia platform are summarized below, while more details are presented in an earlier work [49].

Most of the vAcademia components were developed from scratch. However, some well-known libraries and components were used for programming the networking, image processing, and sound. vAcademia has a client-server architecture and currently works under Windows operating system. The graphical engine of vAcademia was developed specially for the project based on OpenGL. For implementing interactivity in the vAcademia, a Jscript-based scripting language vJs was developed [50].

Large Amounts of Graphical Content in 3D Virtual World are discussed in Sect. 7.3.1. Beyond desktop as immersive technologies is represented in Sect. 7.3.2. Section 7.3.3 provides 3D virtual recording and replay.

7.3.1 Large Amounts of Graphical Content in 3D Virtual World

In this section, an original approach towards displaying large amount of graphical content in 3D VW is presented. It is based on the Stream Processors Texture Generation Model that includes a mathematical model and a programming model.

Mathematical Model. In order to formalize the domain, a mathematical model of image processing by the SPs has been developed based on the specifics of the SP architecture and hardware constraints. The mathematical apparatus of processing 3D graphics by the SPs was simplified to focus only on processing images [51, 52].

The model introduces the basic terms, objects, and their transformations. An image is represented in Red Green Blue Alpha (RGBA) format provided by Eq. 7.1, where $f_R(x, y)$, $f_G(x, y)$, $f_B(x, y)$, $f_A(x, y)$ are discrete functions defined by tabular procedure and corresponding to the color channel with values in the range [0, 1].

$$U(x,y) = \{f_R(x,y), f_G(x,y), f_B(x,y), f_A(x,y)\} \tag{7.1}$$

The result of transformation G of image A based on image B is a modification of the image function (Eq. 7.1):

$$R = G(A,B,x,y). \tag{7.2}$$

A geometrical figure is defined as a set of 2D vectors of vertices V, a set of indexes of vertices F, and a color in $\{r, g, b, a\}$ format provided by Eq. 7.3.

$$S = \{V, F, \{r,g,b,a\}\} \tag{7.3}$$

A rasterization is a transformation of a geometrical figure that has an image as a result, which is described by Eq. 7.4, where G_R is a rasterizing transformation, M_P is a projective matrix, and G_P is a projection transformation.

$$U(x,y) = G_R(G_P(S, M_P)) \tag{7.4}$$

The result of a projection transformation G_P is a projected figure:

$$S_P = G_P(S, M_P). \tag{7.5}$$

In addition, the mathematical formalization was applied to the configurable functionality (of the SPs) that was suitable for image processing tasks. As one of the specifics, the SPs have some configurable (not programmed) functionality, which was formalized and linked to the programmed functionality. This included a mechanism for texture sampling, color mask, hardware cut of the rasterization area, hardware-based blending of the source image and the rasterized image.

The suggested model allows defining the color of each pixel of the resultant image separately as the resultant image is the function of pixel coordinates.

This makes it possible to calculate parts of an image or even single pixels instead of the whole image. The generic nature of the model allows comparing the efficiency of different approaches to any specific image processing task, such as dynamic texture generation, using the formula for image generation time (Eq. 7.6), where T is a time of processing the whole image, T_C is a compilation time of the image processing program (shader) that performs a transformation, T_{TR} is a time of preparation for transformation, T_1 is a time of calculating the color of one pixel, i.e. calculating R (Eq. 7.2), W and H are width and height of the processed image, respectively.

$$T = T_C + T_{TR} + T_1 * W * H \tag{7.6}$$

Programming Model. The mathematical model presented above was used as a base for the programming model and architecture based on four main objects (Texture, Drawing Target, Filter, and Filter Sequence) and a limiting condition <β>.

Texture is an image in format (Eq. 7.1) stored in the SP memory. The image can be loaded to a texture and obtained from it asynchronously (using extension GL_ARB_pixel_buffer_object [53]) with the possibility to check data availability, reducing the expenses of the communication through the data bus.

Drawing Target is an object that defines the resultant image, color mask, and settings of other configurable features of the SPs.

Filter is a subroutine with the main function GetColor that defines the image transformation (Eq. 7.2) and returns the color of a point for the given coordinates. This function has predefined and custom (user-defined) parameters. The GetColor function is defined in GLSL-like language (OpenGL Shading Language) extended with additional functions for image processing. Its parameters are strongly typed, have unique names, and are defined in the form of XML. The GetColor function provides the multipurpose model allowing, for example, to program texture generation as a method of procedural materials and as a method of full periodical texture regeneration.

Filter Sequence (FS) is a sequence of filters with parameters to be used for complex transformations.

<β> is a limitation introduced to the model for securing independent parallel processing of any image blocks.

The models presented above have been used for the original modification of the Discrete Wavelet Transformation (DWT) algorithm [54] for the SPs and an algorithm for rasterizing attributed vector primitives on the SPs [55].

Implementation in vAcademia: Methods and Tools. The Interactive Virtual Whiteboard (VWB) is the main tool (or a container of tools) for collaborative work on 2D graphical content in vAcademia. The rationale behind the design of the VWB was the following. The system should remove the current technological limitations on the number of virtual displays, and allow new working scenarios to be realized in 3D VWs. In addition, it should allow displaying images from multiple sources on the same virtual display at the same time. The following requirements were set. The system should support up to 50 VWBs in the visibility scope of a user. Each VWB should be able to display images from two sources simultaneously and independently. Users should be able to setup the VWBs and use them collaboratively. These major requirements are based on a preliminary evaluation of the needs of common practice [55].

The design of the vAcademia VWB and the tools for collaborative work on graphical content is based on using a dynamic texture with two independent layers, which are combined a single static texture, when rendering. Generally, the lower level is used for permanent content, while the upper level is applied for temporary content that can be changed. This allows having a temporary dynamic figure above several different lower-layer contents (such as slides or sticky notes). In other cases, the lower layer may contain a dynamic image, while the upper layer may remain unchanged (such as commenting in a videos, when the comments must remain visible above all the frames).

A number of collaborative tools have been developed for the VWB in vAcademia [56]. The tools can be classified into three groups by the method of generating the resultant image. In the following, the methods and associated groups of vAcademia tools are presented, including technical requirements, design, and implementation. The requirements for the methods are based on the results of preliminary testing.

Sharing Changing Blocks. The following requirements were set for this method. The system should be able to support up to three simultaneously working image-sharing processes in any location with up to 1,024 × 1,024 pixels resolution each, and with a frame rate at least 5 frames per second. The frame rate is considered as a requirement for the performance of the system only. However, it also depends on the Internet connection speed, and, therefore, meeting the requirements does not guarantee the desired frame rate (in case of low connection speed).

Design: The Sharing Changing Blocks method of generating the resultant image is based on an algorithm for the DWT for image compression with quality reduction, which is adapted for the SPs. It identifies the changing rectangular parts of the image by using occlusion query [57]. The algorithm is based on a filter cascade scheme that allows implementing the forward DWT in one pass. The method uses the lower layer of the VWB and processes the dynamic image.

Implementation 1: Sharing an application window allows to share the content of any window. The window is translated even if minimized or overlaid. The control over the window can be given to any user in the location. This feature can support various scenarios, when a live demonstration of third-party software is required. For example, synchronous collaboration or a hands-on tutorial on a specific application can be conducted by sharing its window (Fig. 7.1).

Implementation 2: Sharing screen area allows sharing any square area on the desktop, which may contain any working applications. This tool can be used in a session, when the use of multiple software applications is required to be shared. For example, a part of the screen can be shared to demonstrate contents in different applications, for example, a web browser and a video player.

Implementation 3: Sharing a web-camera image allows sharing the web-camera image and adjusting its size. This tool can be used for building trust in the beginning of a distance collaborative session, for example, for introducing the

Fig. 7.1 Sharing application window (scratch programming language in the center)

participants. Each of them can use a personal VWB to share the image from the web-camera. Another example is a scenario, when hand gestures or facial expression need to be shared.

Sharing Attributed Vector Figures. The system was required to support simultaneous drawing or typing on up to 25 VWBs with the average performance degradation less than 15 % and peaking performance degradation less than 25 %.

Design: The Sharing Attributed Vector Figures method of generating the resultant image is based on triangulation of vector primitives with attributes for one- or two-way rasterization. Displaying (both typed and inserted) text is implemented by using font textures, rasterizing each symbol on demand. The method uses the upper layer of the VWB and processes the dynamic image.

Implementation 1: Drawing figures and typing text allows to draw, erase, copy, and paste several types of geometric figures and text on the VWB. Drawing and typing actions from the time of cleaning the VWB can be undone. The undo depth is unlimited, which would be a performance prohibitive operation if using CPU only. This tool can be used in multiple collaborative scenarios, when drawing and typing is required, for example, taking notes during brainstorming session, creating mind maps, annotating slides, and sketching prototypes.

Implementation 2: Inserting text tool allows inserting text from the clipboard to the VWB as long as it fits its size. This feature can be used together with drawing figures and typing text, allowing participants to work in third-party applications and share results on the VWBs.

Processing Static Images. The requirements for the method were the following. The system should support simultaneously changing static images on five VWBs within the visibility area. The average performance degradation should be less than 10 % and peaking performance degradation less than 15 %.

Design 1: The Processing Static Images method of generating the resultant image is based on resizing the source image, applying filters, asynchronous unpacking, and uploading it. The method uses the lower layer of the VWB and processes the static image.

Implementation 1: Slideshow allows opening PDF or PPT presentation on the VWB and navigating the slides forward and back. This tool allows replicating meeting settings that are commonly used for presentations. As opposed to the typical physical environment, a presenter can use several screens for slides, and other participants can upload their slides too. The main advantages of the vAcademia's VWB over similar tools in other 3D VWs are that a large number of screens with slides can be deployed in a single virtual location and that the tool is integrated into the system.

Implementation 2: Area print screen allows displaying any square area on the desktop. Image quality can be adjusted. This tool can be used in collaborative activities, when a part of the desktop needs to be presented to all the participants. For example, this can be the result of an individual assignment, which needs to be discussed. Another common situation can be the need to present a quick snapshot that fixes a status of a working application, enabling to compare with the next status later.

Implementation 3: Image insert allows inserting from the clipboard, from resource collection of vAcademia, and from applications (drag-and-drop). Image quality can be adjusted. This tool provides flexibility that is necessary for selecting working material on demand and on the fly.

Design 2: Processing Static Images from 2D scene is based on a fusion of a high number of alpha-blending filters with different source images, blending settings, and hardware scissors. A 2D image or a rasterized image of a letter is taken as an input parameter.

Implementation 4: Backchannel allows displaying text-chat messages on the VWB. An additional tab appears in the text chat of all users in a location, when a backchannel tool in used on the VWB. Messages in this tab immediately appear on the VWB. A backchannel is a powerful mechanism for improving the contact between the speaker and the audience that is becoming increasingly popular and taking multiple technological implementations [58]. Such a simple interaction mechanism can be considered more valuable in a virtual environment as the non-verbal interaction and awareness mechanisms are very limited there.

Implementation 5: Sticky notes tool allows placing text or graphical notes on the VWB. It is a full-scale tool for collaborative work and can be used in a wide range of activities, including brainstorming and project-work discussions [59]. Sticky notes in vAcademia can be placed on any VWB after activating the special mode (Fig. 7.2). Any user can create notes, edit them, move on the surface and between VWBs, remove own notes, and see the actions of other users in real time. The design of the tool has been presented earlier [60].

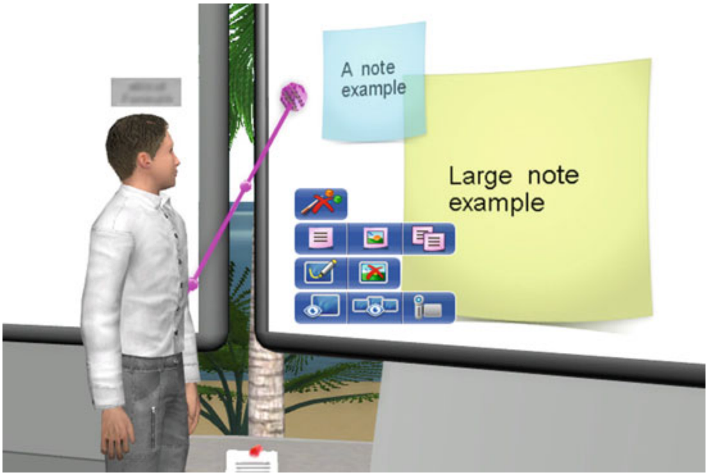

Fig. 7.2 Examples of sticky notes and the tool's context menu

7.3.2 Beyond Desktop—Immersive Technologies

Capturing Real-life Activities with Motion Tracking for 3D Virtual World. The general motivation for integrating a motion-tracking system as an input device for 3D VW is providing users with a possibility to control their avatars with natural gestures. Our specific motivation for designing the vAcademia-Kinect prototype lies in making the users able to conduct meetings, presentations, and lectures in the physical and in the virtual world at the same time, controlling their avatars and media content on the screen with natural gestures [61].

The vAcademia-Kinect first prototype. The virtualizing real-life activities mode interface is implemented using the *vAcademia Scripts* (Fig. 7.3). The Scripts initiate the beginning and the end of this mode. In addition, the Scripts provide the Kinect-related information including the skeleton in 2D and the recognition status of each body part.

The Scripts interact with the Animation library of the graphical engine through the Script Executing Library. The Animation library interacts with the Kinect plugin and, based on the data from it, controls the user's avatar using Cal3D (Fig. 7.3).

vAcademia uses Cal3D library for implementing the skeleton avatar animation [62]. It allows to control the skeleton of an avatar by constantly and automatically recalculating its polygonal 3D model to match the current state of the skeleton. In the first prototype of the system [63], the Animation library of vAcademia requested a set of key points of the user's body from the Kinect-support plugin. If the user was recognized by Kinect, Cal3D bones of vAcademia avatar were oriented according to the key points. In the general case, the user is considered standing,

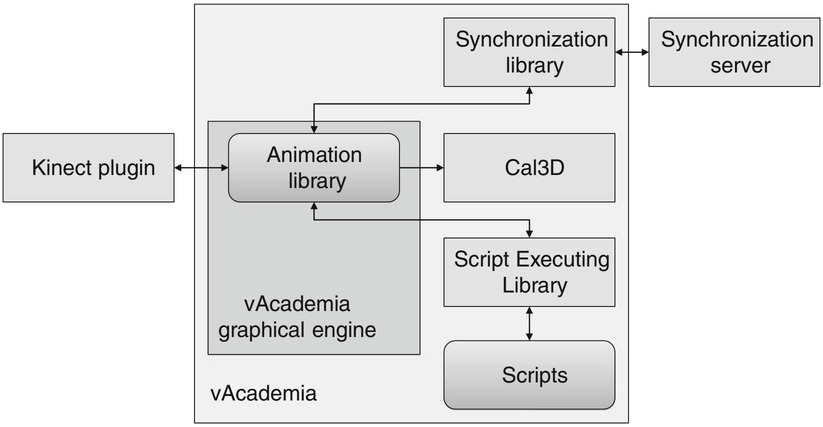

Fig. 7.3 Virtualizing real-life activities mode interface of vAcademia

which is defined as a "standing mode". The system also supports a "sitting mode", when the motion-capture data are used only for orientating arms and head.

In addition, Kinect provides the status of each key point of the presenter's body (not recognized, presumably recognized, or recognized) as well as indicates, if the body is cut in one of four directions by the camera visibility area. In order to eliminate unnatural poses, the skeleton is divided into five major parts (arms, legs, and head) to process the Kinect data for them separately. If a part of the skeleton remains unrecognized adequately for 0.2–0.5 s, the system sets it into a default state.

vAcademia requires and actively uses one CPU core. Other cores may be also used but less actively (10–30 %) except for the process of the first load of the VW data. Kinect requires a dual-core CPU but uses only one core as the second is reserved for the application that uses Kinect data. These settings define the requirements for the computer to run the system designed.

The information on the key points acquired from the Kinect device is synchronized so that the avatar controlled by the Kinect moves identically for all clients of the VW. All necessary data is assembled to an avatar binary state and passed to the Synchronization library (Fig. 7.3). The Synchronization server sends out the binary state to the other clients of the VW, where it is interpreted as if the data is received from a local Kinect device.

Although the evaluation has not been systematic so far, it allowed us to improve many characteristics of the system. Several evaluation sessions were conducted in several physical auditoriums with different configurations and lightning. The major evaluation data source has been an interview with the presenter. The following feedback on the technological setup is the most common.

The system applies too many restrictions on the movements of the presenter. First, the presenter has to stay in the area in front of the Kinect device, and a space between them should be clear. Second, the presenter has to face the device and not turn away. Third, the presenter has to use only one hand for pointing at the screen. Fourth, the presenter has to avoid gestures that are difficult to recognize, when translated into 3D VW.

Increasing the sense of immersion with Head-mounted displays. The motivation for integrating an HMD with 3D VW is to improve the user experience allowing a more natural navigation in the environment and increasing the sense of immersion. The vAcademia-Oculus Rift HMD prototype improves the immersion to the virtual environment and, therefore, increases the engagement by providing a more sophisticated visual and navigation experience. A particular key difference such a fusion of technologies makes is the mobility of the HMD user in comparison to the stationary PC.

The vAcademia-Oculus Rift prototype. The development of a mode that supports Oculus Rift HMD has been done according to the Software Development Kit (SDK) provided by Oculus VR. However, an original approach has been adopted to increase the level of system performance. The standard scheme for Oculus Rift support contains three rendering passes. First, the image for the left eye is rendered, second, the image for the right eye, and then the images are combined by a filter transformation, when they are displayed in the screen (Fig. 7.4).

The new approach applied in vAcademia reduces the number of rendering passes to two at the cost of applying a more complex filter (see the Programming model in Sect. 7.3.1) that transforms two images simultaneously for both eyes. Rendering of left-eye and right-eye images is conducted in parallel on the same surface. Then, the transformation is done using a filter that is more complex than in the standard scheme. It allows conducting the transformation for both eyes simultaneously and applying a post effect (Fig. 7.5).

In the process of implementing the transformation, the shader suggested by Oculus Rift SDK was found to produce visual distortions on high objects, when turning the head (with the viewpoint). The principle of a better realization of the shader has been acquired from the source code of a viewer provided by CtrlAltStudio.

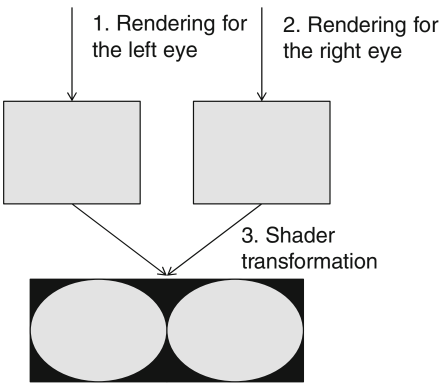

Fig. 7.4 Standard Oculus Rift support scheme

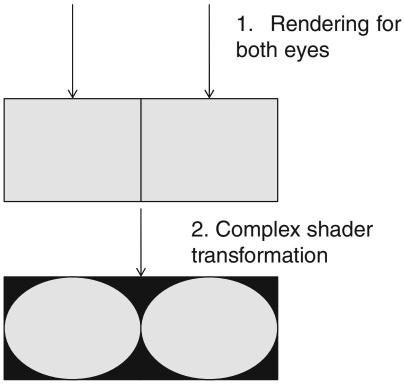

Fig. 7.5 Oculus rift support in the vAcademia

In order to provide a convenient mechanism for avatar control while using the Oculus Rift HMD, the xBox controller has been employed. One of the controller's joysticks is used for moving the avatar forward, back, strifing left, and strifing right. The other joystick is used for turning the avatar left and right along the vertical axis.

7.3.3 3D Virtual Recording and Replay

The technology of 3D virtual recording and replay allows a new type of media content that might have its own set of practical applications. The 3D recording stores rich data in a format that preserves the original course of activities with all the details. This allows accessing "raw" virtual experience, when replaying (or re-visiting) a 3D recording. Assuming that information and knowledge may be stored not only in tangible artifacts (such as written instructions and databases) but also in activities, practices, relations between participants, and in their shared experiences, a 3D recording and replay provide a better access to the latter category [42, 64].

3D Virtual Recording Concept. The most distinctive feature of vAcademia is a 3D recording or virtual recording. It allows capturing everything in a given location in the VW in process, including positions of the objects, appearance and movement of the avatars, contents on the whiteboards, text and voice chat messages [49]. Similar functionalities were earlier realized in a few VWs or desktop virtual reality systems. However, 3D recording was never developed into a convenient tool and never adopted for specific use as in vAcademia. In addition, no convenient tools for working with the resultant recordings were developed.

A 3D recording allows creating a new type of media content and supports new types of collaboration. The new media can be called "virtcast"—a 3D recording of activities in virtual reality or a series of such recordings [65]. This type of content is user-generated as a process of creating and sharing 3D recordings is fully automated.

A user can attend and work inside a recorded virtual session, not just viewing it as a passive spectator. In addition, any recorded session can be attended by a group of users. A new group can work within a recorded session and record it again but

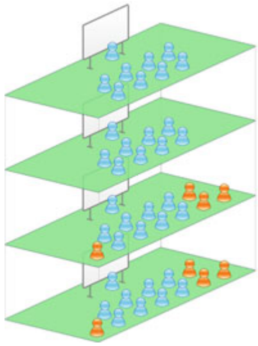

Fig. 7.6 Layering realities using 3D recording in vAcademia

with their participation. Thus, there is an opportunity to build up content of recorded sessions, and layer realities on top of each other (Fig. 7.6).

From the user point of view, a 3D recording control is similar to the regular video player. A 3D recording can be fast-forwarded and rewound, paused, and played again from any point of time. A replayed 3D recording is perceived exactly like a live virtual session. Of course, the recorded avatars will always act the way they were recorded. However, it is possible to use all the functionality of the VW inside a recording. Moreover, a replayed 3D recording can be recorded again together with new actions. In such way, new recordings and new content can be created based on the same original event.

Storing 3D Virtual Recordings and their Data. The 3D virtual recording may contain different resources such as media content. Resources can appear and disappear multiple times during a virtual session. They have to be managed and stored in 3D VW as well as linked to states of the world in the obtained virtual recording.

vAcademia has a storage for such resources called Resource Collection [49]. It can be used for uploading, storing, and sharing resources in 3D VW. The Resource Collection has three sections with different access rights including a public collection (for all users), a private collection, and a virtual session collection (for the participants of a particular virtual session). Each user can store presentations in PPT format, documents in PDF, pictures in PNG and JPEG, and 3D objects in Collada and 3DS.

Mathematical Model for Storing 3D Virtual Recordings. The 3D virtual recording is described by Eq. 7.7, where t is a time from the beginning of the recording, O_i is an object in a recorded location, and $f_i(O_i, t)$ is a discrete function of the object transformation over time.

$$P(t) = \{f_i(O_i, t), f_{i+1}(O_{i+1}, t), \ldots, f_n(O_n, t)\} \tag{7.7}$$

Equation 7.7 represents that components of 3D recording can change in parallel, i.e. any number of objects can change any number of their properties at any point of time.

In order to make the mathematical model represent the data required for 3D replay, Eq. 7.7 can be written as follows:

$$P(a) = \{B_1, B_{2,} \ldots, B_n\}, \tag{7.8}$$

where a is an identification number of the author of the 3D recording and B_i is a data set required for replaying ith object in 3D recording $P(a)$.

In its turn, B_i can be described by Eq. 7.9, where O_i is an object in a recorded location, $A(t)$ is a function of time for the synchronized object, and R_i is a data set of resources required for replaying the object O_i in 3D recording.

$$B_i = \{O_i, A(t), R_i\} \tag{7.9}$$

If a resource $r \in R_i$, Resource Collection can be described by Eq. 7.10, where R_g is a public collection data set, R_a is a private collection data set, and R_l is a virtual session collection data set.

$$R = \{R_l, R_a, R_g\} \tag{7.10}$$

In order to manage resources of 3D recording remote fragments, a counter variable is attached to each resource. When a resource is used in 3D recording, the associated counter is incremented. When the counter is equal to zero, the associated resource can be removed to the server archive. Thus, the notion of a resource is extended and represented by Eq. 7.11, where $r_i{}'$ is an extended resource and J_i is a counter of links to the resource in all 3D recordings.

$$r_i' = \{r, J_i\} \tag{7.11}$$

The 3D recording in its turn can be described by Eq. 7.12, where N_R is an number of all 3D recordings and $N_S(k)$ is a size of data set P_k.

$$J_i = \sum_{k=1}^{k<=N_R} \sum_{m=1}^{m<N_S(k)} H(P_K, B_M) \tag{7.12}$$

The function $H(P_K, B_M)$ is defined by Eq. 7.13.

$$H(P_K, B_M) = \begin{cases} 1 & \text{if } \exists \text{R: } r \in R \text{ and } R \in B_M \\ 0 & \text{otherwise} \end{cases} \tag{7.13}$$

Thus, a resource can be removed from the system, if it is removed from all Resource Collections, and the counter of links is equal to zero i.e. if a set of equations (Eq. 7.14) is fulfilled.

$$\begin{cases} J_i = 0 \\ \forall R \qquad r \notin R \end{cases} \tag{7.14}$$

If only the first condition is fulfilled, the resource is moved to the server archive.

3D Virtual Replay System Design. The system of 3D virtual replay is closely integrated with the synchronization system. The latter implements the identical appearance of the 3D VW for all users at any point in time. It also saves the data necessary for recreating the state of the world during 3D virtual replay. Synchronization of the VW state is achieved by securing equivalence of the objects' extended states. In vAcademia, an extended state of an object defines a set of parameters required for the visualization of the object and, most importantly, parameters of the actions performed by the object to recreate the behavior of the object over time and visualize it for each user.

For each object functionality type, there is a model of possible extended states and transitions between them. Changes in object extended states happen much more rarely than changes of its visual state. Therefore, the synchronization system operates extended states. A model of some avatar extended states is described as an example (Fig. 7.7).

Complex sub-states "Stand", "Walk", "Sit", and "Run" represent the fact that some of the states are mutually exclusive. However, an avatar can be in other sub-states "Speak into microphone" and "Type into text chat" simultaneously with others. All complex sub-states contain data describing the state. It allows the system to re-create the same state when the avatar exit and re-enter the VW. Therefore, there is no exit from the state "Avatar in the virtual world" on the diagram (Fig. 7.7).

A 3D virtual replay differs from the video playback. In a video recording, frame is the elementary unit. However, in a 3D virtual recording, object action is the elementary unit, and it can be instant or continuous. The continuity of some of the actions makes it difficult to recreate the state of objects at any point in time (e.g., in the middle of a continued action). However, it is required for important tasks including fast-forwarding and editing 3D virtual recordings [66].

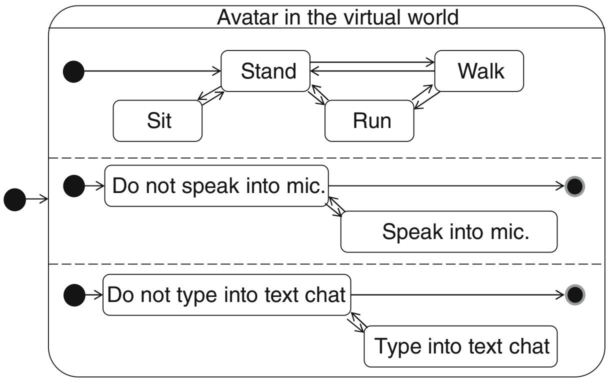

Fig. 7.7 State diagram of some avatar extended states

Control Points and Complete State of 3D Virtual Recordings. While a 3D virtual recording is being created, *control points* are created at certain intervals. Control point of 3D virtual recording is a set of *complete states* of all objects in a recorded location. Complete state of a virtual object is a set of all its synchronized properties. Continuing the parallel to the video, a control point of a 3D virtual recording is similar to a key frame of a video recording.

When fast-forwarding during virtual replay, the closest to the lower side in time control point is found first. Next, the complete states of all objects are sent to the software clients of all users. Finally, all changes in synchronized properties that occur from the time of control point to the sought point are sent.

Keeping the performance level acceptable in such tasks is challenging. First, the system has to apply all changes in extended states of objects that occur from the last control point of 3D recording. Second, synchronization data that are stored in the 3D virtual recording often contain links to resources (e.g., media content). The network traffic and the computational power required for these processes are high.

Processing Continued Actions. In order to process continued actions, each of them receives a variable for time shift from its beginning. This variable is processed by client software. Equation 7.9 can be written in a view of Eq. 7.15, where B_i' is an extended data set of synchronized object properties and T is a time shift.

$$B_i' = \{B_i, T\} \tag{7.15}$$

The requirement of time invariability of continued action execution has been set to ensure the correct work of this approach. It means that when replaying a synchronized action, the object audio-visual properties will coincide for all users (i.e. software clients) independently of any circumstances, such as processing or network delays.

A different approach is used for synchronizing the continued actions of drawing on a VWB. The drawings are represented as a set of primitives with their properties [55]. All these data for each VWB are stored as a single binary storage. There are two actions defined over the binary storage: clear and write into the end. Thus, when the system needs to re-create the drawing during a virtual replay, the binary storage that existed on the server at the required moment can be applied.

3D Virtual Recording Use Cases. In this section, several 3D virtual recording use cases are elaborated to illustrate its functionality. A 3D recording is a new trend in 3D VW technology, and, therefore, its potential is not yet fully discovered. This feature raises the use of recording to a new level, providing a possibility for active work inside a recording. Collaborative activities with 3D recordings or virtcasts can be conducted in two basic formats: first, visiting 3D recording, and second, creating a new 3D recording while conducting activities being inside one.

Visiting 3D virtual recording is similar to working with a video recording or a recorded webinar. It is possible to watch 3D recording at any convenient time focusing on some parts and skipping the other ones. However, 3D recording differs significantly from other recording methods. First, 3D recordings can be visited by a group of users, who can actively work inside the recording. Second, 3D recording is a copy of a live session, but it is not different from the original. Inside 3D recording at any point of time, all the objects are on the same positions as they were in the live session. All the interaction that happens in 3D recording can be observed in the same way as in the live session. However, the visiting avatars cannot interact with the recorded ones.

The second format—creating a new 3D recording, being inside one is even more different form the other types of recording. The 3D-recorded session can be visited with the same or a different group of users and recorded over again. As a result, another 3D recording will appear, containing new discussions, questions, and comments. Working inside 3D recording, the users can use all the functionality of the VW.

A simple procedure is required to access the second format of working with 3D recordings:

1. Loading existing 3D recording (see R_1 in Fig. 7.8)
2. Starting recording by pressing the corresponding button (R_2 is being recorded now)
3. Playing recording R_1
4. Conducting activities in the environment
5. Fast forwarding, pausing, and stopping R_1 when necessary
6. Stopping recording R_2
7. Saving R_2 in the database

It is possible to pause (see the "add" pieces in Fig. 7.8) and fast-forward/stop (see the "skip" pieces in Fig. 7.8) the original 3D recording, extending some of the parts and cutting the others. In such a way, the skipped parts of the original recording will not appear in the new one. At the same time, some new actions, recorded while the original recording was paused, will appear (Fig. 7.8).

Recording new activities being inside 3D recordings allows creating additional virtual content. Activities in the new layers of 3D recordings can focus on specific parts extending and improving the original one or providing multiple variations of an activity. In such a way, vAcademia allows editing content of asynchronous recordings of synchronous activities. 3D recording creates new possibilities for combining synchronous and asynchronous collaboration in a single platform. This feature is especially useful in the cases, when a certain activity has to be repeated frequently.

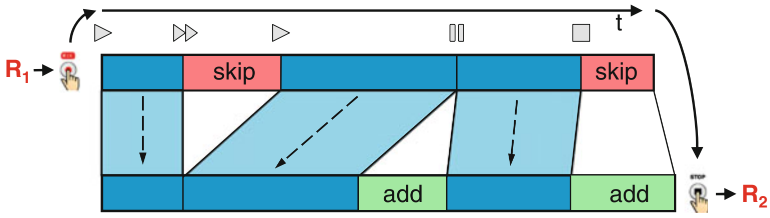

Fig. 7.8 Creating a new 3D recording, being inside one

7.4 Results and Discussion

This section provides the evaluation results of fusion of the main components described above: natural interfaces, large amounts of graphics, and virtual recording. The advances and challenges for further development and practical use are discussed such as a fusion of motion capture, graphical content, and virtual recording (Sect. 7.4.1), a fusion of HMD, multiple virtual screens, and virtual recording (Sect. 7.4.2), and a fusion of large amount of graphical content, 3D space and virtual recording (Sect. 7.4.3).

7.4.1 Fusion of Motion Capture, Graphical Content, and Virtual Recording

Applying Kinect for Motion Capture in vAcademia. The evaluation of the first prototype (see Sect. 7.3.2) revealed three major limitations of Kinect in the given context and three corresponding challenges for the system implementation:

- C1: Kinect does not capture the gestures accurately enough. Therefore, an attempt to build a reliable avatar model that excludes unnatural poses was not successful.
- C2: Kinect does not recognize the turning of the presenter. If the presenter turns away from the device, it mixes up the left and the right.
- C3: An obvious, but serious challenge for applying Kinect is its inability to capture parts of the body that are covered by other body parts or foreign objects.

Challenge C1 has been addressed by introducing several mechanisms. The distance between the Kinect device and the presenter has been limited. In addition, the Kinect device has been fixed at a 0.5 m distance from the floor. An additional filtration mechanism for sorting out unnatural positions has been introduced, separating hands as distinct body parts.

Challenge C2 has been addressed by implementing the following algorithm. The turning is recognized relatively as a function of the position of the pelvis end points. The resultant value is valid within the range from −110 to 110 degrees against the "facing Kinect device" direction. Colored markers have been introduced for better recognition of the turns (Fig. 7.9).

The video data acquired from Kinect is analyzed using the SPs. The mathematical model presented in Sect. 7.3.1 has been extended by a function of the projected figure template Eq. 7.16, where G_R is a rasterizing transformation defined in Eq. 7.4, a value of B_R shows, if the rasterized figure covers the pixel defined by x and y.

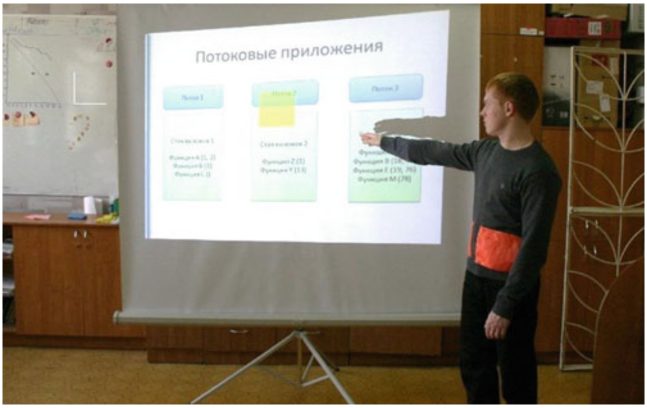

Fig. 7.9 Presentation capturing process

$$B_R(x,y) = \begin{cases} 0 & \text{if } G_R(x,y) = \emptyset \\ 1 & \text{if } G_R(x,y) \neq \emptyset \end{cases} \tag{7.16}$$

Using Eq. 7.16, another function was defined for the number of pixels in the projected figure in the rasterized image—Eq. 7.17, where S_P is a projected figure defined in Eq. 7.5.

$$N_m(S_P) = \sum_{x=1}^{W} \sum_{y=1}^{H} B_R(x,y) \tag{7.17}$$

The image is processed by a filter that returns the color of the pixel, if the pixel does not correspond to the color of the marker with specified error. If Eq. 7.17 returns the value higher that defined, the system considers that the markers are recognized and the presenter is within the allowed turn range. If the returned value is lower, the system stops using Kinect data until the markers are recognized again.

Challenge C3 may be addressed by applying multiple Kinect devices. It may also contribute to improving accuracy and turn recognition. At the same time, new challenges may appear such as the increase of the price, complexity in setting up the system, and complexity in merging the data from multiple sources.

Applying Kinect and iPad for Controlling Virtual Whiteboards in vAcademia. Based on the results of the system's first prototype evaluation, the following challenges for controlling virtual whiteboards and their contents have been identified:

- C4: The position and movement of the presenter against the physical whiteboard should match the position and movement of his/her avatar against the virtual one.
- C5: A physical pointer needs to be captured and represented in 3D VW, where it is often even more important. However, Kinect cannot capture a physical pointer.

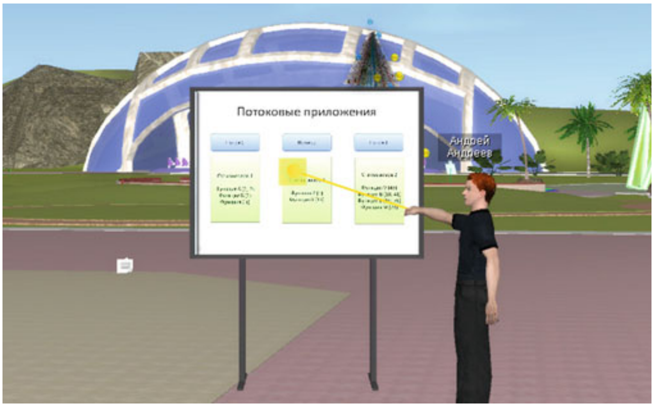

Fig. 7.10 Presentation streaming process

- C6: Switching the slides requires interaction with the computer or a remote control, which does not convey any meaning when captured and translated into 3D VW.

Addressing C4, a Setup mode has been introduced for achieving the precise match between the physical and the virtual whiteboard (horizontally) and installing Kinect at 0.5 m from the floor (vertically). Instead of trying to capture the physical pointer, the virtual pointer is directed based on the position of the presenter's hand, addressing C5. If the half line that extends from the presenter's hand crosses the physical whiteboard, the avatar in 3D VW directs a virtual pointer to the same point (Fig. 7.10). In order to keep the presenter aware of his/her hand being captured, a semi-transparent yellow area on the physical whiteboard is displayed on top of the slides (Fig. 7.9).

Addressing C6, the switching slides functionality has been developed to recognize standard Kinect gestures Swipe Left and Swipe Right. In addition, a tablet mobile device (iPad) has been included into the system as an optional interface extending the possibilities of controlling media contents. Using vAcademia Presentation Remote app, the presenter can stream handwriting and drawing to a VWB and control other content on it without going back to the computer. The tablet is connected to the vAcademia client software through the vAcademia communication server using access code [63].

7.4.2 Fusion of HMD, Multiple Virtual Screens, and Virtual Recording

The fusion of an HMD technology with using multiple VWBs and 3D virtual recording is promising. Even though the technologies are implemented under a single platform, the evaluation of them working together is still underway.

Working with Multiple Virtual Screens wearing a Head-Mounted Display. The fusion of an HMD interface and the multiple virtual screens has been technologically successful. It solved the problem of switching the view between multiple screens. As was indicated in the related work, there are both 2D and 3D technologies that can facilitate remote collaborative work with multiple screens that display various media content. In 2D system, the display can be either split into sections or contain several screens that can be minimized and restored. In 3D system, the virtual screens can be installed in any order (e.g., around the avatar of the user). However, the amount of computational and networked resources required to support such a setup is large.

The two technological components of the discussed fusion allow, first, displaying a large amount of virtual screens in 3D space keeping the performance level acceptable and, second, switching the view between these screens in the most natural way i.e. by turning a head with an HMD.

The current realization of this fusion of technologies is being tested only internally, and a full-scale user evaluation is needed to confirm the benefits. However, the first serious challenge has been already discovered. The Oculus Rift HMD has a much smaller image resolution in comparison to regular modern desktops. The current realization includes the first Oculus Rift Developer kit that has the resolution of 1,280 × 800, which means only 640 × 800 per eye. In addition, the Filter transformation (see the Programming model in Sect. 7.3.1) further reduces the amount of visual information in the screen (Fig. 7.5, step 2). This technical limitation does not allow using this fusion of technologies fully. One of the key characteristic of the approach for displaying large amounts of graphical content in vAcademia is high quality of graphics. The approach was meant for high-resolution graphical content that is viewed on a low-resolution display in the system.

Still, the technology of HMD is now rapidly developing, and Oculus VR released Developer kit 2 with the screen resolution 1,920 × 1,080 (960 × 1,080 per eye) and a possible increase in the consumer version. These resolution values will move the visual experience closer to the desired level and allow a user evaluation of the system.

3D Virtual Recording and Replay with a Head-Mounted Display. This fusion of technologies constitutes one of the most promising directions for future research work. The current realization of 3D recording processes users with Oculus Rift HMD in the same way as users that work with the regular desktop client software. In the resultant 3D recording, all participants will appear as regular avatars regardless of the interface their users have been using during the recording. However, the viewpoint data of users can be visualized.

In most cases, the viewpoint data in 3D VWs provide little or no valuable information for the users or the system. These data are not collected or visualized in 3D VWs and similar systems. This fact can be partly explained by the low accuracy in matching the viewpoint with the focus of the user's attention. In addition, visualizing such data can obstruct the view. However, using an HMD, users control their viewpoint in a way that is much closer to the one in the physical world. This can be exploited by the system but visualized in a virtual replay instead of the live activity. This would allow avoiding the obstruction of the users' view but provide valuable information visualized and easily accessible through the virtual replay.

In the current realization of the system, users can take any position and viewpoint as well as change them while replaying 3D recording. However, visiting users will always be third-party observers. The fact of wearing an HMD will only change the observer's experience. This raises a question, whether 3D recording can be experienced through the eyes of each participant. The fact that changing the viewpoint with an HMD in 3D VW is similar to the physical world makes this use case viable and promising. It will allow a more detailed analysis of virtual recordings and actions of particular participants.

Cybersickness. One of the challenges associated with the use of HMDs and Oculus Rift in particular is so-called "cybersickness" [67]. Testers of early prototypes/development kits of Oculus Rift exhibit some problems such as motion sickness/nausea, loss of peripheral vision and latency when moving the head [68], especially when there is a mismatch between body position in the simulation (walking) and in reality (sitting). Prolonged and safe usage requires that these problems are solved in the coming versions. It also requires adjustment of usage modes, for example, limiting time intervals with the Oculus and switching between different usage modes during the working session [69].

7.4.3 Fusion of Large Amount of Graphical Content, 3D Space and Virtual Recording

This section provides the results of testing the tools available on a Virtual White Board (see Sect. 7.3.1). In particular, the discussion considers the combination of 3D space and large amounts of meaningful 2D graphical content.

Such combination required a new approach. 3D VW had to display large amounts of 2D graphics without overloading the CPU with computations. In order to achieve this, some of the core images processing algorithms (such as discrete wavelet transformations and rasterization of attributed vector figures) have been adopted to work on the SPs instead of CPU. The results of the evaluation demonstrated significant improvement in performance. The implementation of image processing algorithms on the SPs excels the performance using only CPU computational power tenfold and more [55].

Next, the general efficiency of the system has been evaluated, i.e. its performance degradation, when using many VWB tools simultaneously, measuring the average and peak values. In the following, the average results of the evaluation are presented.

Using 3D Virtual Recording for Evaluation. The process of evaluation of the system efficiency relied on another component of the technological fusion suggested in the chapter—3D virtual recording. It was used to ensure the equivalency of the virtual evaluation scene for each test run and to simplify the process. The data

Fig. 7.11 The process of testing performance degradation as a function of the number of VWBs

were collected by replaying 3D recording on different hardware configurations. For each configuration, the number of simultaneously working tools was regulated by excluding the required number of VWBs from a re-played 3D recording (Fig. 7.11).

The data were acquired by running the system on 20 different hardware configurations with Intel CPU and NVidia/ATI graphics adapters from the same price range. On each hardware configuration, 10 runs were conducted [55].

General Efficiency of the System with Large Amounts of Graphics in 3D Space. The results are demonstrated by the ratio of the average and peaking performance degradation to the number of simultaneously working VWBs, actively used VWBs, and simultaneous changes of images on the VWBs [55]. The *average* values are calculated as the arithmetic mean of all measurements took in all runs. The *peaking* values are calculated as the arithmetic mean of the maximum measurements took in each run. The analysis of data reveals that 50 simultaneously working VWBs reduce the performance of the client software by no more than 7 %, while 4 % is the average value. The peaking performance degradation reaches 22 %, when the number of actively used VWBs is equal 25. The average performance degradation reaches 13 %. Five simultaneous changes reduce the performance of the system by 14 % in the worst case and by 8 % on average.

The results acquired during testing indicate that all the performance requirements for the tools for collaborative work on 2D graphical content were satisfied [55]. However, the quality of the visual content displayed in the VWBs is an essential characteristic for the most of the collaboration use cases. Therefore, the method is designed to ensure the quality of the generated image. Generally, a higher image resolution provides a better visual quality. However, increasing the resolution leads to significant losses in performance.

The proposed approach was designed to mitigate performance loses with the increase of the resolution of the processed images. These design principles were

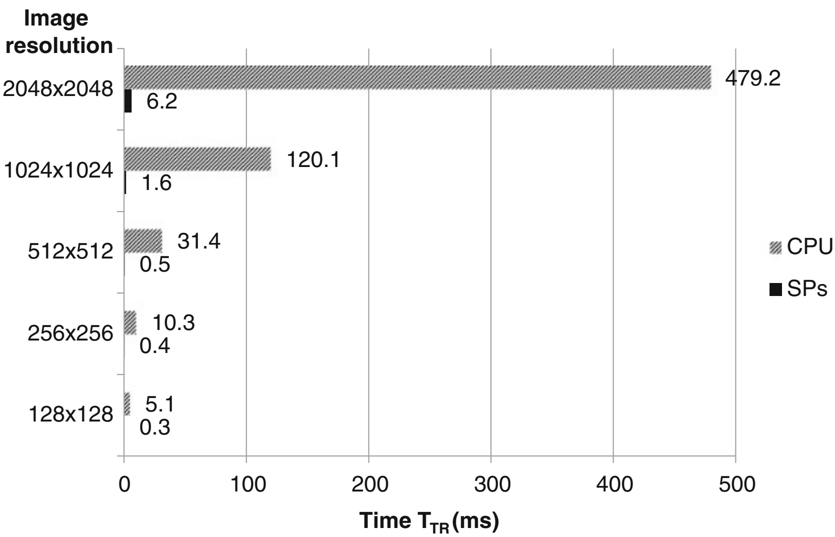

Fig. 7.12 Image packing preparation time

evaluated by comparing the performance of typical algorithms for images of different resolutions implemented using the SPs and CPU. The algorithms selected for the evaluation are the packing (Fig. 7.12) and unpacking (Fig. 7.13) of images using forward DWT. These algorithms are used for the implementation of the Sharing Changing Blocks method (Sect. 7.3.1). The indicative parameter measured in the test is the time of preparation for transformation T_{TR}, defined in Eq. 7.6. The SPs-based algorithms were run on four computers with NVidia GF8800 GT, while the CPU-based algorithms were run on four computers with Core 2 Quad 2.4 G (all four cores were used). For each image size, 1,000 runs were conducted on different images.

The data demonstrates the advantage of SPs over CPU for given algorithms riches 77 times for packing and 44 times for unpacking the image. However, the most valuable outcome of this test is that the maximum advantage is achieved for images of higher resolutions. The processing time for both algorithms does not grow exponentially or even linearly with the increase of image resolution. This means that the system can operate images of high resolution and quality without losing much of the performance. Lower performance of the unpacking algorithm on the SPs is caused by the higher number of rendering passes used. The non-linear relation between T_{TR} and image resolution is caused by the significant time values of the rendering pass in these algorithms.

The results acquired in both performance and quality tests demonstrate that large amounts of meaningful 2D graphical content can technically be displayed in 3D VW. This means that a fusion of 3D space and large amount of 2D graphics has been successful. It enables new scenarios of use for 3D VW and improves the user experience. In addition, 3D virtual recording proved to be a useful fusion component.

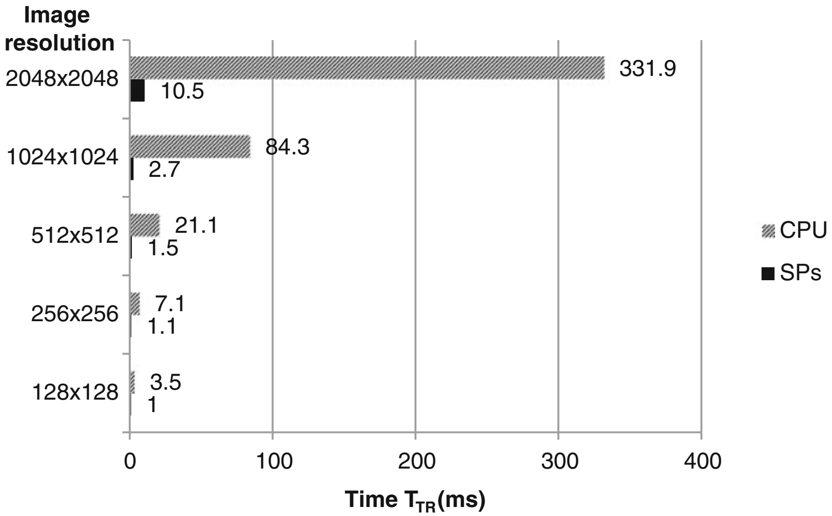

Fig. 7.13 Image unpacking preparation time

7.5 Use Case Scenarios

In this section, the fusion of technologies described above is discussed in light of how it could support various collaborative activities in the business settings, for example, meetings and collaborative teamwork. In order to structure the discussion, a collaboration model is used.

Collaboration is a complex activity that requires support at all stages to be effective and successful. Three main components of the collaborative process should be considered according to the collaboration standard [70]. The first component is *collaborative workplace*—an instantiated independent entity, consisting of two other components *collaborative group* that performs collaborative activities according to roles by means of a *collaborative environment* consisting of tools [70]. The technological support of these components in the vAcademia allows conducting various collaborative activities that are illustrated by the scenarios below.

In the following scenarios (Sects. 7.5.1–7.5.3), a fictional multinational company *A* that develops and sells medical equipment is used.

7.5.1 Scenario 1: Annual Shareholder Meeting

The company is holding its annual shareholder meeting in its head office. The collaborative group assigns the roles of presenters and attendees. The collaborative environment is enhanced with several vAcademia tools. In particular, the fusion of motion capture, graphical content, and virtual recording (Sect. 7.4.1) is used.

The movements and slides of the presenter are captured with Kinect and recreated in designated virtual offices of company *A* in vAcademia. Therefore, a presentation can be followed both by co-located audience and by shareholders, employees, and customers in other parts of the world. The highlights from the financial results are presented on multiple VWBs in the virtual office. The virtual recording of the meeting is stored in the database on the company's own server for later reference. This can be seen as an asynchronous enhancement of the collaborative workplace.

7.5.2 Scenario 2: Working with Customers

A potential customer considers ordering medical equipment from company *A*. The collaborative group consists of a customer and a company representative. The collaborative environment used is the fusion of the HMD, multiple virtual screens, and virtual recording (Sect. 7.4.2). The customer logs into vAcademia using Oculus Rift. He/she is met online by a sales representative from one of the company's offices, not necessarily in the same geographic region. The representative leads the customer to one of the virtual demo halls exhibiting equipment used during neurosurgical operations. The collaborative environment is a virtual exhibition hall that has a section designed as a surgery room. The customer is using Oculus Rift to examine the equipment in full 3D mode. The sales representative might invite the customer to a virtual recording showing a simulation of an operation, where the use of the equipment is demonstrated. The customer might want to update the recording using other tools of the collaborative environment, for example, comments and additional specifications (recorded with voice, sticky notes, and written comments on the VWBs). The new recording will then be used further by the sales and development teams to deliver the final product to the customer in accordance with his/her specifications. The customer can also get a copy of 3D recording that contains the entire experience of the meeting with company representative including the comments made during the demonstration. Such recording can be seen as a different collaborative workplace, when it is used later by different collaborative groups with additional roles both in the customer company and in company *A* (e.g., Scenario 3).

7.5.3 Scenario 3: Working in Distributed Teams

When receiving an order from the customer in Scenario 2, one of the international teams is assigned to the task. The team holds a meeting inside the virtual recording with the customer's comments and discusses how the customer's specifications might be met from a technical perspective. In this scenario, the collaborative group consists of various experts from company *A*. At the same time, the collaborative group from Scenario 2 is also a part of the activity. The meeting and brainstorming is recorded again with additional discussions and comments from the experts (including written comments on sticky notes and diagrams on the VWBs). It appears that meeting the customer's specifications requires involvement of the second group of specialists in a different office of the company. These specialists review the virtual recording with the comments from the customer and their colleagues. The quality of the content on the VWBs is high enough to see all the details, and the system performs without visible delays. Based on the outcomes, the second group of specialists develops a set of alternatives solutions that are presented in multiple VWBs that are accessible to the other team and the customer.

7.6 Conclusions and Future Work

This chapter outlines the possibilities for fusion of technologies on the base of 3D VWs. Prospective benefits of such fusion and technological challenges are discussed, and possible scenarios of use in a business context are suggested. The realization of these scenarios requires, however, a seamless integration of technologies and addressing the challenges identified in Sect. 7.4 in the future.

Another direction for future work will be exploring additional possibilities for fusion of technologies, combining 3D VWs with low-cost VR components and interface elements. For example, paraphernalia used with Oculus Rift already include a large range of devices. Apart from keyboard, standard game consoles, and motion sensor controllers such as Kinect and Razer Hydra are used. Possible paraphernalia include mobile phones and tablets, exoskeletons, haptic interfaces, and omnidirectional treadmill devices such as Virtuix Omni. Developing realistic simulations of different working modes and business processes might require additional/dedicated tools as well as flexible combinations of different usage modes.

Finally, the adoption of new technologies will inevitably affect usage patterns and collaboration modes. A more throughout exploration of different scenarios and work patterns that could be supported by the fusion of technologies in different areas such as business, public service, and entertainment are necessary for further development of the field.

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Chapter 8
Fusion of Multimedia and Mobile Technology in Audioguides for Museums and Exhibitions

Jean-Pierre Gerval and Yann Le Ru

Abstract This chapter introduces software developments targeting visitors in museums. The main idea leading to these projects is to implement low cost systems that would provide visitors with informational contents about paintings, artworks, etc. The first application was achieved by means of a system that sends a multimedia content (images, audio and texts) to a visitor's mobile phone, when the mobile phone is in communication range of a Bluetooth transmitter. The second application is an authoring tool that does not require any software development skill. Curators can set up easily and quickly contents for the visitors. Experiments took place in a Marine Park, where more than 200 contents had been developed. It is a web-based system. On smartphone side, HTML5, JavaScript, and Ajax technologies enable us to target a wide range of devices. In the last part of the chapter, these two approaches are compared, and also, taking into account the experiences, some new opportunities of developments are declared. In the last part of the chapter we compare these two approaches and we also open some new opportunities of developments taking into account our experiences.

Keywords Audioguides · Authoring tool · Bluetooth · Exhibitions · Multimedia · Museum · Smartphone · Web

8.1 Introduction

This chapter sets out software developments and experiments targeting visitors in museums. Nowadays most people own a smartphone. Most of them use their smartphone to listen to music, to watch videos, to keep in touch with their social

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networks, etc. This chapter aims to describe new approaches in the field of audioguides development that fit with these new technologies. Our motivation for the development of such tools is twofold.

On the one hand, a goal is to replace existing audioguides systems in order to reduce exploitation costs. Existing systems require specific equipment. They are expensive to buy and to maintain. In some museums, the technologies used are out of date, and budgets for culture granted by the public authorities are rarely rising. Using visitors' smartphone is a good way to reduce investments and maintenance costs. However, some world-renowned museums have larger budgets, for example, the Louvre museum. The Louvre Audio Guide [1] is available on App Store or Google play for iPhone or for Android. The Louvre museum also rents Audio Guide on Nintendo 3DS. There are 3D photos of the galleries, high-definition images, and 3D reconstructions. On the other hand, the aim is to increase the interest of young people by means of new tools that implement new technologies. Museums do not always have the reputation of being attractive to young people.

Two types of developed applications are represented in this chapter. The first one is based on the Bluetooth connection to a server and suitable for small painting exhibitions (Sect. 8.3). The second type of applications is dedicated to a large exhibition and uses a database with stored and edited content. Visitors have get access to information through a content generator (Sect. 8.4). Section 8.5 provides discussion and prospects of this work.

8.2 Background

In the first part of this chapter, we describe an application, which was developed for a small painting exhibition. This development had been achieved with the municipal Museum of Pont-Aven [2]. This museum was created in 1985 in order to promote the artists, who drew their inspiration from Pont-Aven. The well-known Pont-Aven School emerged around Paul Gauguin in Brittany between 1886 and 1896.

The main idea, which leads to this work, is to implement a low cost system that will provide visitors with informational content about paintings. Such a system can replace traditional audioguides that are rented to visitors.

Multimedia contents are pushed on the smartphones (either mobile phone) of the visitors by means of a Bluetooth connection to a server. In [3], authors discuss about "*how to transmit and install software for audioguides and to evaluate the interoperability of different devices regarding to the technology*". They conclude that "*Bluetooth is the most attractive way to provide software for audioguides in a museum or exhibition, because it is a cost effective way to transmit data*". One disadvantage of this solution is the complexity of the installation process. In our application, we pay special attention to the usability of the installation process: the user just has to activate Bluetooth in his/her smartphone and to wait for the content to be downloaded.

A quick overview of developments in this field points out at first the use of a Personal Digital Assistant (PDA) that supports interactive applications to deliver rich media, such as audio and video, to visitors. An interactive handheld museum guide on Pocket PC [4] was developed, implemented, and evaluated by the Blanton Museum of Art at the University of Texas at Austin in collaboration with UT's Information Technology Department. The evaluation pointed out that a majority of visitors were satisfied. In addition, technical lessons were learned, for example: battery life was too short; Pocket PC was fragile; Pocket PC was easy to use, "*even by people with no prior computer or handheld experience…*". Nowadays, battery life is getting longer but attention should be paid to offer visitors solutions to recharge their devices when necessary. In our experiments, we are targeting visitors' smartphones. It can be expected that the visitors take care of their smartphones.

It is confirmed by [5] that one of the best improvements for their system was making the PDA more reliable. They also point out that: "*The best way to distribute the PDAs and teach visitors how to use them was a constant work in process*". We wish to avoid such a situation that appears, when the PDAs are rented or lent to visitors.

The same finding stands in [6], where authors had experimented an audioguide based on the Apple iPod touch: "*The operations of an audioguide are explained and learned in seconds, while any PDA class device requires minutes, a time span unbearable in large museums*". We can expect that using visitors' smartphones is a good way to reduce the time that the visitors need to understand operations.

In their work concerning a location sensitive multimedia museum guide [7] authors point out that "*users tend to stop playing audio media after a specific time*" and that "*users want more audio instead of text content*". This is an interesting fact that we have to take into account: audio or video files that are too long can distract visitors from the goals of the exhibition. We also have to be aware that "*the richness of the personal interactive multimedia technology risks to divert the user's attention from content to presentation*" [6].

Other examples of developments [8–10] provide more added values to visitors by means of objects recognition in museums based on images, which are taken directly by the visitor. The image is sent to a server; objects are recognized, and then the requested information is sent to the visitor. These applications are exciting but they require many types of equipment such as the PDA or tablet PC, network infrastructure and servers with database. Such applications are well suitable for large museums. It "*saves museum curators from distributing and maintaining a large number of physical (visible or invisible) tags*" [10].

A Radio-Frequency IDentification (RFID) may also be associated to the PDA [11]. The PDA RFID readers identify the related objects. Detailed content is then downloaded via the wireless network and presented on the PDA. Such a technology sounds appropriate for large rooms, where artworks are not too close to each other. The authors found that: "*an interaction distance of approximately 15 centimetres between the HF RFID tag and the reader was reasonable. If the distance was too large, the reader sometimes simultaneously detected multiple tags*".

In our case, we were requested to provide a low cost system. For that reason, we pay attention to mobile phones and smartphones. No need to provide any equipment to visitors because most of them own a mobile phone.

A lot of museums use mobile phones for tours, especially in the US. But it is not "*the great democratic tool for reaching new audiences in Europe*" [12]. On the one hand, many museums in Europe are located in historic buildings, where mobile phone reception is poor. On the other hand, a lot of Europeans have 'pay-as-you-go' plans and so, higher per-minute call costs [12].

In order to avoid any additional cost for visitors, the idea is to push content (a multimedia application: images, audio, texts) to clients (mobile phone or smartphone), when they are in communication range of a Bluetooth transmitter. There are many advantages for that solution:

- There is no cost for data transfer.
- The content is stored on the visitor's side and can be read at any time anywhere.
- The content can be easily transferred from one mobile phone to another.
- The visitor is requested to accept or refuse to download the content.
- It is easy to use and does not require any specific knowledge from the visitor.

The second part of the chapter is dedicated to a large exhibition. The aim is to provide "on-demand" multimedia contents to visitors and there are several hundreds of contents to design. This development had been achieved in cooperation with Océanopolis [13], a scientific Marine Park:

- 9,000 m^2 of exhibition space.
- 3 pavilions: tropical, polar, temperate.
- 68 aquariums.
- 4 million litres of seawater.
- 1,000 species.
- 10,000 marine animals.
- Close to 400,000 visitors per year.

The challenge was twofold. On the one hand, it was to provide audioguides on visitors' smartphones at a large scale. On the other hand, it was to ensure that content development was as simple as possible.

There are many contents and there are many visitors using smartphones. This leads us to think about implementing a web solution to pull contents from the smartphones of the visitors. Most of the previous references deal with mobile applications that are targeting visitors. They rarely give details about the design of contents for museum.

In 1998, Hertzum [14] identified three typical problems faced by museum web sites:

- "*The majority of the museum sites have been developed without a clear notion of what the site should achieve.*"
- "*The sites have not been evaluated to find out whether they match the users' needs and wishes.*"

- "*The material on the sites tends to duplicate material in the physical museums rather than to rethink it given the possibilities provided by the new medium.*"

We believe that these three typical problems must be taken into account, even if our target is to develop an audioguide system. With the advent of mobile media in museums, the crucial from a design point of view is to define precisely, what we offer as contents to the visitor and what we consider as necessary in the "Here and the Now of the practice" [15]. A study on mobile phone tours and audioguides at the Centre Pompidou in Paris [16] suggested the need for "*innovative multimedia search and navigation tools*" to cross-reference objects, information, and keywords.

In [17], there are also recommendations for a user-centred development of museum web sites. In our case, we will focus on two kinds of users: curators and visitors.

When developing contents, special attention must be paid to design, information retrieval, and reusability of contents. As it is suggested in [18], a model based on domain ontologies can enhance the informational potential of objects in a museum catalogue. It can ensure reusability of information. It may allow curators to work more efficiently, for example, in identifying the relationship between a particular object and contexts of knowledge.

Different types of ontologies can be distinguished according to [19]:

- "*Domain ontologies*" representing knowledge for a particular domain (e.g., mechanic, electronic, medicine).
- "*Metadata ontologies*" describing the content of on-line information sources.
- "*Generic or common sense ontologies*" that aim at providing general knowledge about the world (e.g., time, space, state, event).
- "*Representational ontologies*" providing representational entities without stating what should be represented.
- "*Method and task ontologies*" providing a reasoning point of view on domain knowledge.

According to the context of our developments, we have established three ontologies:

- A domain-specific ontology.
- A metadata ontology.
- A common sense ontology.

The domain-specific ontology (Fig. 8.1) as mentioned above provides knowledge on a particular domain. Such ontology should be established by curators.

The metadata ontology (Fig. 8.2) is linked to the domain-specific ontology by means of topics of interest that are chosen from the curator's point of view. This ontology is particularly interesting for the design of the Conceptual Data Model of the database. According to [20], concepts are organized via semantic relationships:

- Hypernymy: the taxonomic relationship ensures the inheritance of properties between concepts.
- Meronymy: the component relationship between concepts.
- Synonymy: the identity relationship that describes the similarity in meaning.

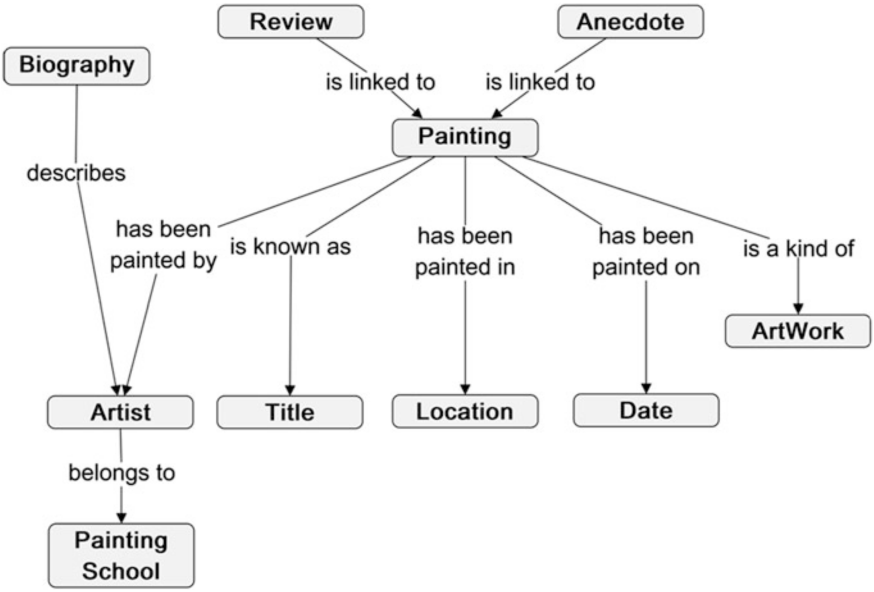


Fig. 8.1 Example of domain-specific ontology

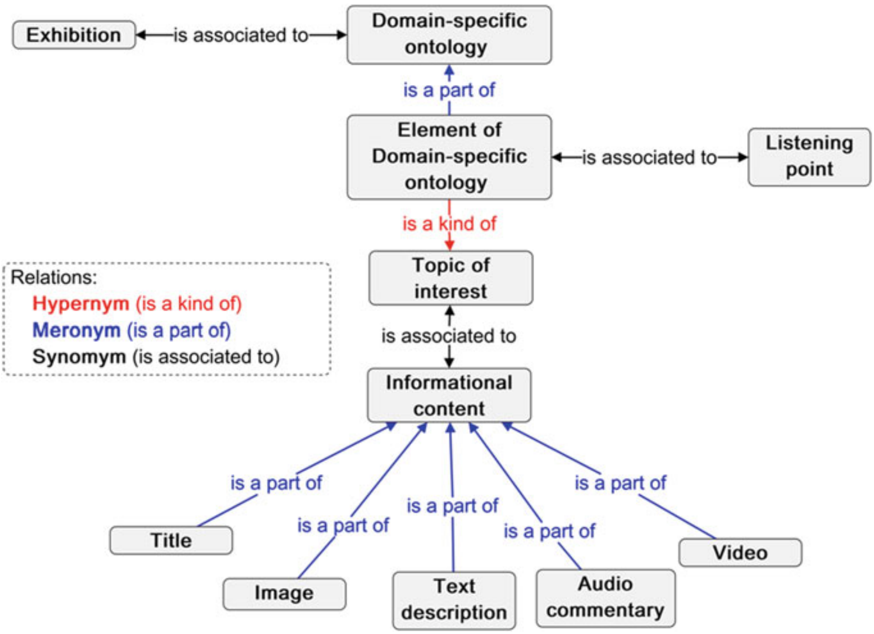


Fig. 8.2 Example of metadata ontology

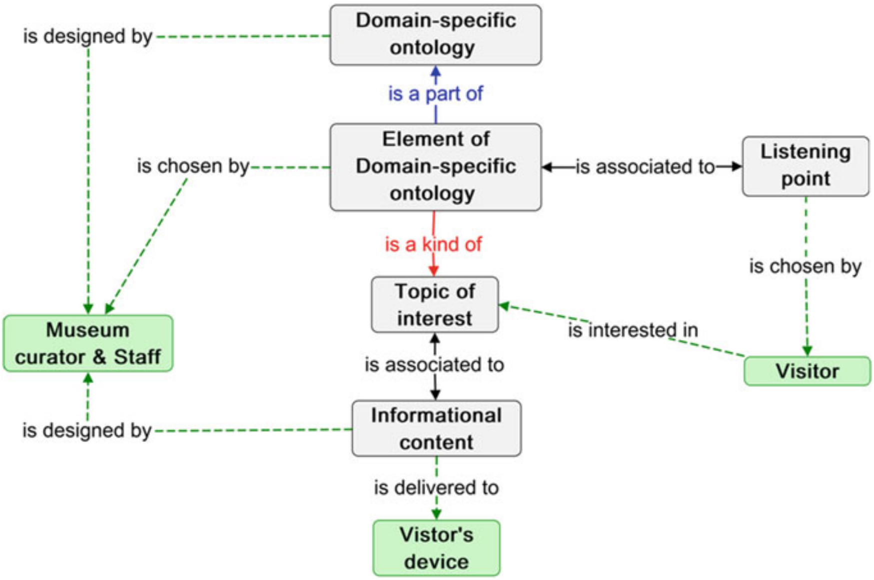


Fig. 8.3 Example of common sense ontology

The common sense ontology (Fig. 8.3) acts as a Use Case Diagram showing the usage requirements for the system: events and/or actions between users and the system.

Given the large number of contents to be designed, an authoring tool (back office) was developed. This tool enables the curators and the museum staff to design their own contents by themselves. New contents will not require any new deployments. It is not necessary to modify and to compile any source code. This means that museum staff do not have to use any software development tools. Our motivation for the development of such an authoring tool lies in the fact that most curators have poor knowledge of web development and "*the staff's skill is critical in facilitating the didactical focus of such a roll-out*" [21]. We also provide curators with a data loader that retrieves elements from an Impress OpenOffice document and imports data into the database.

A quick market survey points out some existing tools [22, 23] that offer content generation by means of friendly interfaces targeting the web, IOS, Android, etc. But they require knowledge in the handling of tools or they require some knowledge in web design such as HTML or CSS. Our goal is to provide tools that do not need any computer skills from Museum staff. That is to say, a tool that is easy to use and simple to understand. Another problem lies in the fact that contents could be stored in the "Cloud". Due to intellectual property or plagiarism, most curators prefer to store their contents either on their own computers or on their local network.

In the last part of the chapter we compare these two approaches and we discuss about advantages, disadvantages and complementarities of such applications. We also open some new opportunities of developments taking into account our experiences.

8.3 Bluetooth Push

A short description of hardware is represented in Sect. 8.3.1. Server and client software is discussed in Sects. 8.3.2 and 8.3.3, respectively. Experimentation is situated in Sect. 8.3.4.

8.3.1 Hardware Requirements

Visitors need to use mobile phones or smartphones that support Bluetooth wireless technology. The Bluetooth transmitter (Fig. 8.4) has been implemented on a personal computer. This was a request from the museum but Bluetooth Access Points that achieve the same job can be found on the market for a cost that does not exceed 400 €. An example can be viewed in [24].

Fig. 8.4 Bluetooth transmitter

8.3.2 On Server Side

On the server side, the software is in charge of transferring the content to mobile phone or smartphones clients. This application has been developed using the BlueCove library [25], which is a Java library for Bluetooth. The OBject EXchange (OBEX) protocol was chosen for data transfer because it is commonly available on mobile phones or smartphones that support Bluetooth wireless technology.

The software architecture (Fig. 8.5) is multithreaded. The main thread is in charge of discovering clients. The other threads are dedicated to data transfer to clients.

The basic behaviour of the server is shown in Fig. 8.6. After initializing the Bluetooth device, we load configuration data: file name to transfer to clients, timeout for discovering clients, maximum number of clients to be served during one loop, duration to keep clients that were served into clients list (in order to avoid sending file to clients that were already served).

After loading configuration data, a three-step infinite loop starts:

- Discovering new mobile phone clients.
- Sending data to new clients that were discovered.
- Finally, updating the list of clients that were served.

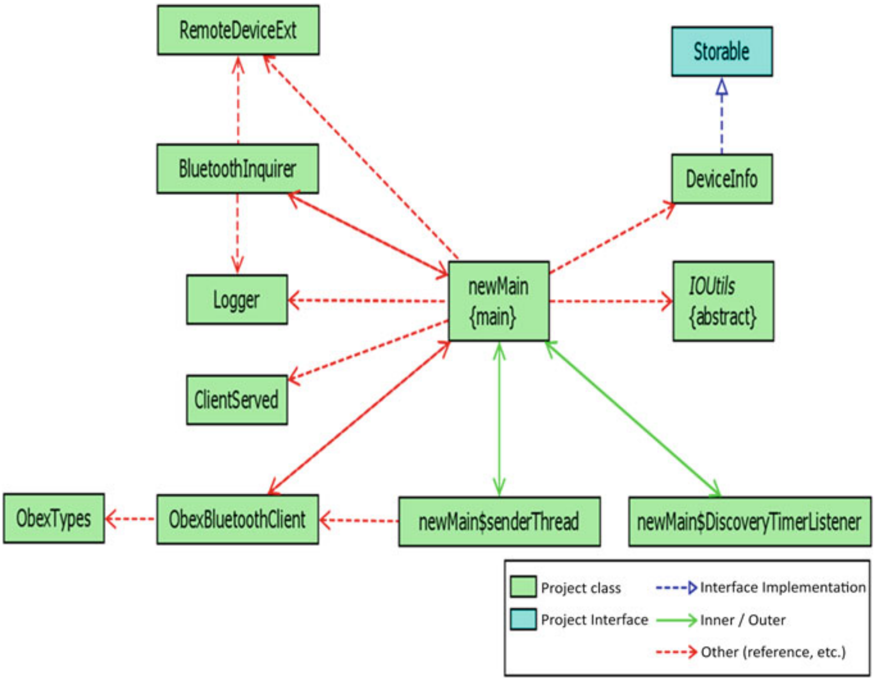


Fig. 8.5 Server UML diagram

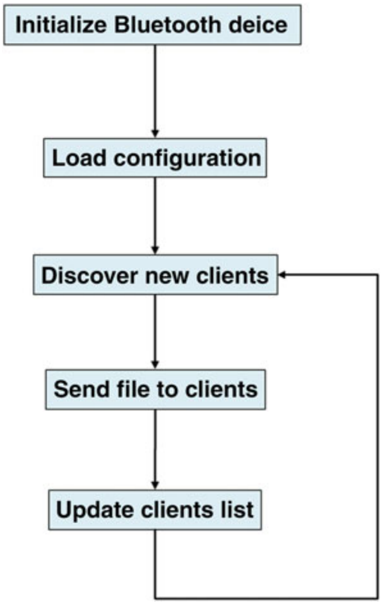


Fig. 8.6 Server side: data processing

8.3.3 On Client Side

The client software has been implemented using Java 2 Micro Edition (J2ME) [26] and J2ME Polish [27]. These clients are especially dedicated to mobile phone, personal assistant, and smartphone. The J2ME Polish provides tools for mobile Java and cross-platform development.

The main features of J2ME Polish include:

- A flexible User Interface toolkit; for example, standard J2ME applications can be designed using a Cascading Style Sheets (CSS) text files.
- Tools that enable the porting of an application to different equipment and also different operating system; for example, it is possible to compile the same application for an Android or a BlackBerry device.
- Software components that enable the implementation of a Remote Method Invocation (RMI) for accessing server side content and communicating with remote parties.
- Software components that make complex data persistence on devices easier.
- A large database of devices.

The content was designed so that changing data does not require changing any source code. Data are stored in folders (Fig. 8.7).

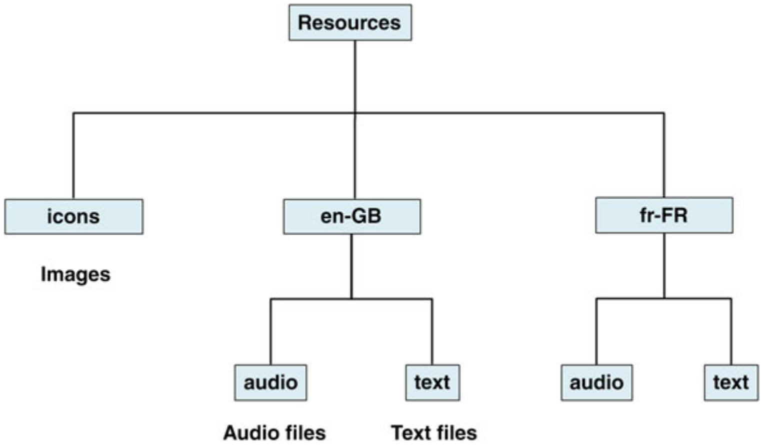


Fig. 8.7 Data: images, audio files and text files

It is easy to set up a new client application:

- The first step is to copy the right files in the right directories.
- The second step is to re-compile the client software.
- This way this application can easily be reused for new upcoming exhibition.

The visitor must choose a language (French or English) before getting access to the main menu. This menu shows the name of the paintings, for which contents are available. When a painting has been selected, the visitor can decide either to read the text or to listen to audio comments (Fig. 8.8). A paradox of the project was the fact that using mobile phone was not allowed in the museum. As a constraint, we had to set the volume of audio files as low as possible.

8.3.4 Experimentation

The experimentation (Fig. 8.9) was carried out for 6 months. The exhibition received more than 30,000 visitors.

The main feedbacks were as follows:

- A lot of visitors were interested in this innovative proposal.
- The most receptive public with this application was the young public.
- Some visitors had difficulty in downloading contents and thus to use these comments while visiting.
- Those, who were not able to download the application, gave up.
- Downloading the application to mobile phone or smartphone was too long while there were only fifteen paintings that were described in this application.
- It would have been more efficient to provide one application per language. Thus, the size of the application would have been smaller.

Fig. 8.8 Choosing a language, a painting, and a viewing data

Fig. 8.9 Inside the museum

8.4 Authoring Tool and Web Pull

Section 8.4.1 provides a description of server software. Authoring tool functionalities are presented in Sect. 8.4.2. A data loader providing a data transfer from OpenOffice to the database is located in Sect. 8.4.3. Client software is considered in Sect. 8.4.4. Finally, experimentation is drawn in Sect. 8.4.5.

8.4.1 On Server Side

The system is built around a database (Fig. 8.10), where contents are stored. Content designers will feed the database using the Authoring tool. Visitors will get access to informational contents through a content generator (Fig. 8.11).

The database contains all the information required by the system:

- The contents of audioguides.
- The default configuration values of the system.
- The access codes and templates for the printing of tickets.

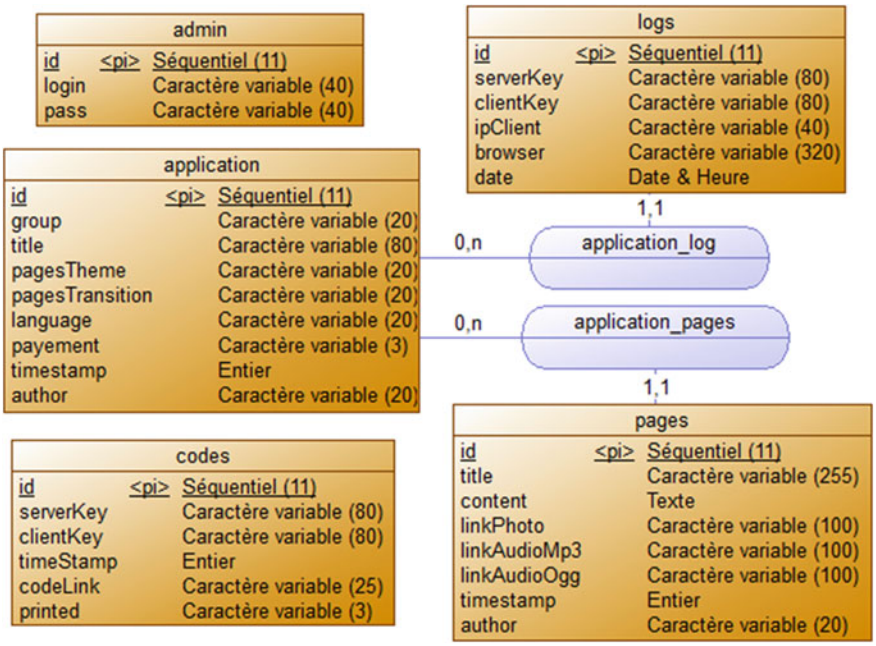


Fig. 8.10 Database: conceptual data model

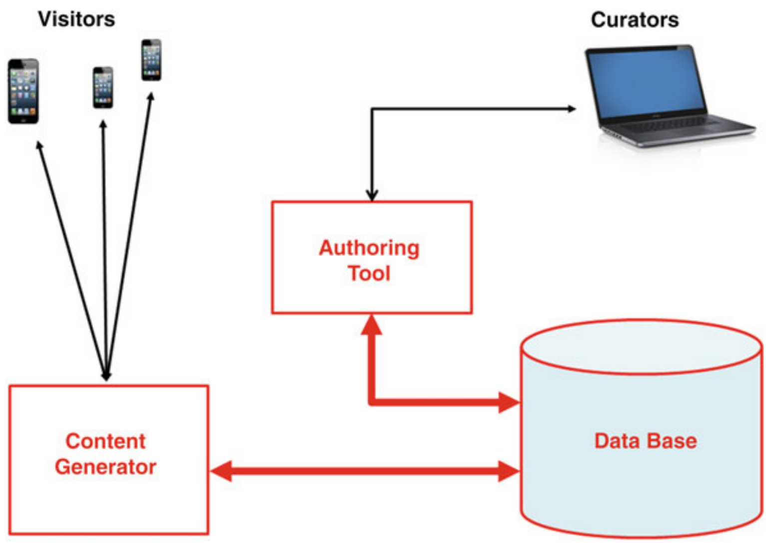


Fig. 8.11 System overview

The contents of the audioguides are structured hierarchically (Fig. 8.12):

- A group is a set of applications that deal with the same topic. For example, it could be the same content provided in different languages. The visitor will get content according to the language they have chosen or according to their

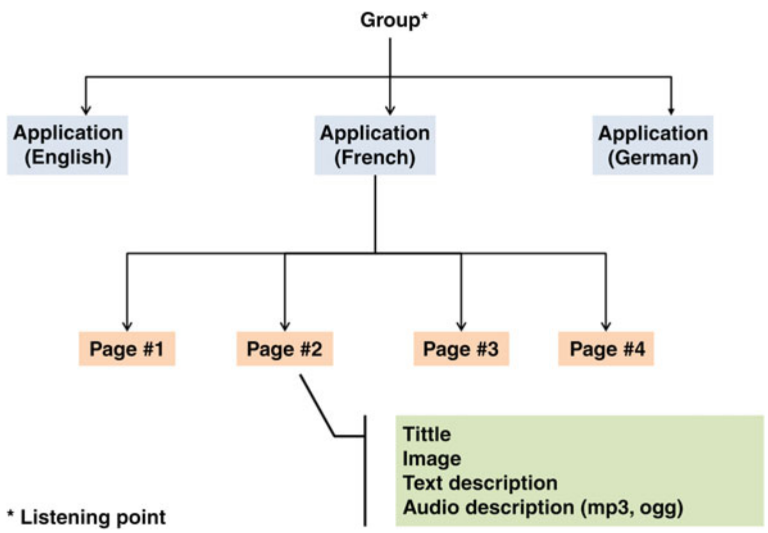


Fig. 8.12 Content organization

smartphone configuration. Generally, a listening point number is associated to a group inside the museum or the exhibition.
- An application is a set of pages that describes a given topic. An index is generated that gives access to each of them.
- A page is a basic element of content. Each page may contain a title, an image, a textual description, and an audio description.

The content generator extracts data from the database and provides HTML5 pages through a template according to a theme and a type of transition between pages that have been defined by the content designer. The template is as simple as possible. It defines the look and feel of the content that will be viewed by the visitor.

This template has been implemented using jQuery Mobile [28]. The jQuery Mobile is a framework that enables the design of responsive web site and applications. This way web sites and applications are accessible on various devices: smartphones, tablets, desktops. Using HTML5 [29] allows us to provide content for various types of smartphone. The HTML5 is the 5th major revision of the core language of the World Wide Web: the HyperText Markup Language (HTML). This way contents are viewable on visitors' own mobile devices. Contents are portable whatever the operating system. There is only one restriction at the web browser level: to be fully HTML5 compliant.

In order to avoid lost or weak network connections and to improve the reliability of our system, we use the cache-manifest functionality of HTML5 that enables web contents to be viewed offline. The addresses of any resource that is required by the application to be rendered are copied into a manifest file. These resources are stored in the local cache of the web browser. In case of failure of the network connection, the web browser will use the local copies instead and will render the web application offline.

The Server and database implement Linux, Apache, MySQL and PHP. This architecture has come to be known simply as LAMP.

8.4.2 Authoring Tool Functionalities

The Home tab. The active application is shown on the Home tab (Fig. 8.13). This is the application, which is currently under editing. By default, we provide the content designer (i.e. a curator) with its first application retrieved from the database.

The Applications tab. This tab (Fig. 8.14) enables the content designer to add a new application or to modify an existing application.

An application is defined with the following arguments:

- A group name (i.e. a listening point number).
- A title.
- A colour theme.

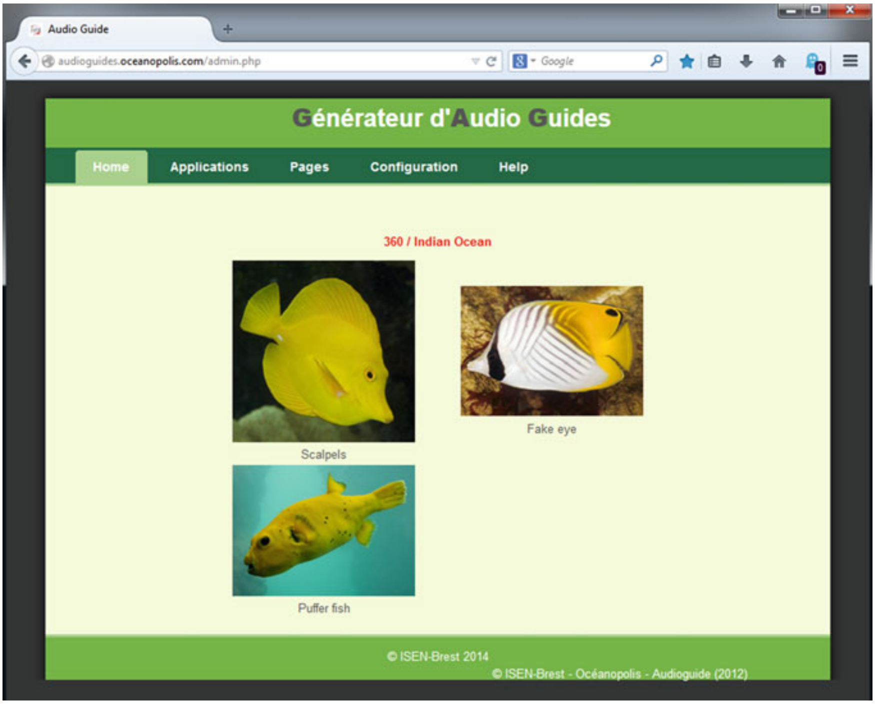


Fig. 8.13 Home tab

- A type of transition between pages: slide up, slide down, etc.
- An attribute that defines the language of the application.
- An attribute that defines the free availability or not of the application; in this case an access code will be required in order to access the content.

The functionalities that enable applications management are the following:

- Deleting the application. All the pages of the application will also be deleted.
- Generating a QR code (Fig. 8.14) that will contain the URL of the application. QR codes are generated using an open source library: PHP QR Code [30].
- Copying the application in another group (or in the same group with another name). This could be useful for example to create a template for a new application in another language.
- Previewing the application (Fig. 8.15). A new window is opened and it emulates the application as if it was running on a smartphone.
- Editing the application. In that case the application runs into the active state and its pages can be edited. The active application is showed in red in the interface.

Fig. 8.14 Applications tab: generating a QR (quick response) code

The Pages tab. The Pages tab is dedicated to the management of pages. A page is defined with the following elements (Fig. 8.16):

- A title.
- An image: we suggest that users provide a 200 × 200 pixels image as the screen of a smartphone is generally small.
- A textual description.
- An audio description: mp3 and/or ogg file. If there are two files the browser will choose automatically, the one it can play.

Functionalities that enable pages management are the following:

- Deleting a page.
- Pushing up a page in the page list.

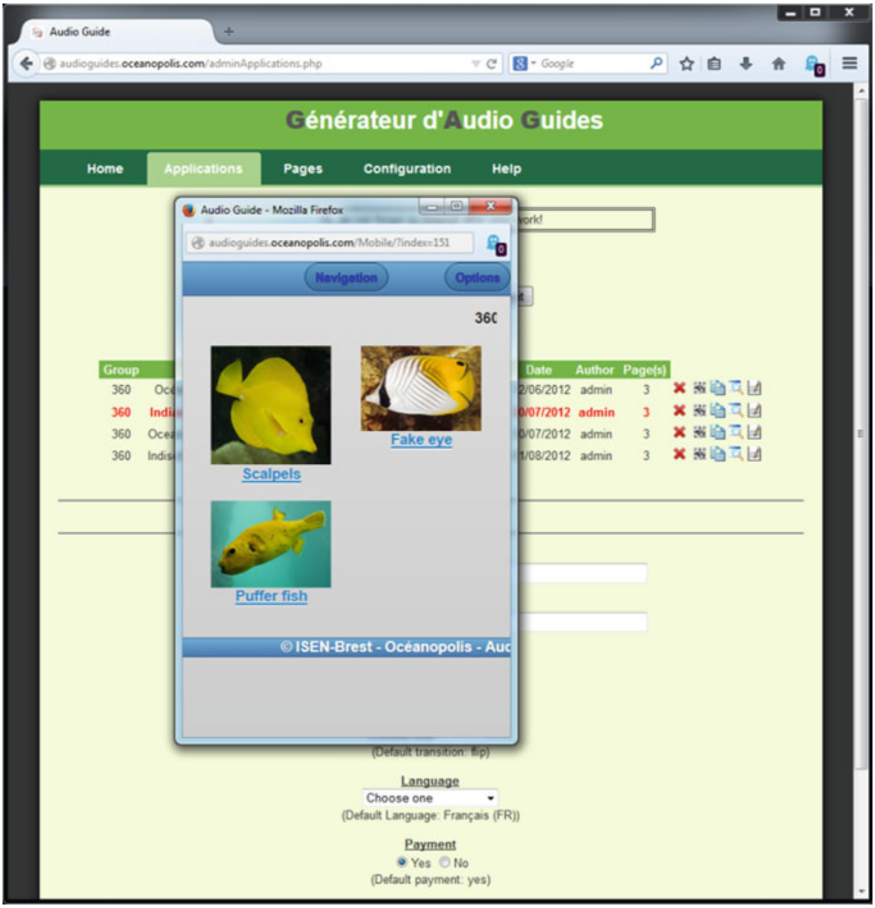


Fig. 8.15 Applications tab: previewing the application

- Pushing down a page in the page list.
- Moving a page into another application.
- Copying a page into the same application or another one.
- Previewing the page. A new window is opened and it emulates the page as if it were running on a smartphone.
- Editing the page. In that case the page runs into the active state and it can be edited.

The Configuration tab. The configuration tab (Fig. 8.17) is only available to administrators. They can define the default values of some attributes or parameters about applications and pages. The configuration tab also offers functionalities that enable the management of tickets and access codes: generating new access codes, printing tickets, deleting obsolete codes from the database, etc.

Fig. 8.16 Pages tab: editing a page

Some applications can be protected with an access code. In order to view protected contents, the visitor must buy a ticket (Fig. 8.18) and scan a QR code that contains the access code before having access to contents that are not freely available.

A server key, which is stored in the database, is used to generate a QR code of the ticket. A client key is generated when the visitor scans this QR code. This client key is stored in the database and also in the memory of the browser using HTML5 local Storage Object (Fig. 8.19). This way is not possible to use the same ticket on different smartphones, and the client key will not be deleted, when the browser is closed. Then the client gets access to all protected contents during his/her visit in the museum or the exhibition (Fig. 8.20). A time stamp is also recorded in the database. This way the lifetime of a protected content can be limited in time.

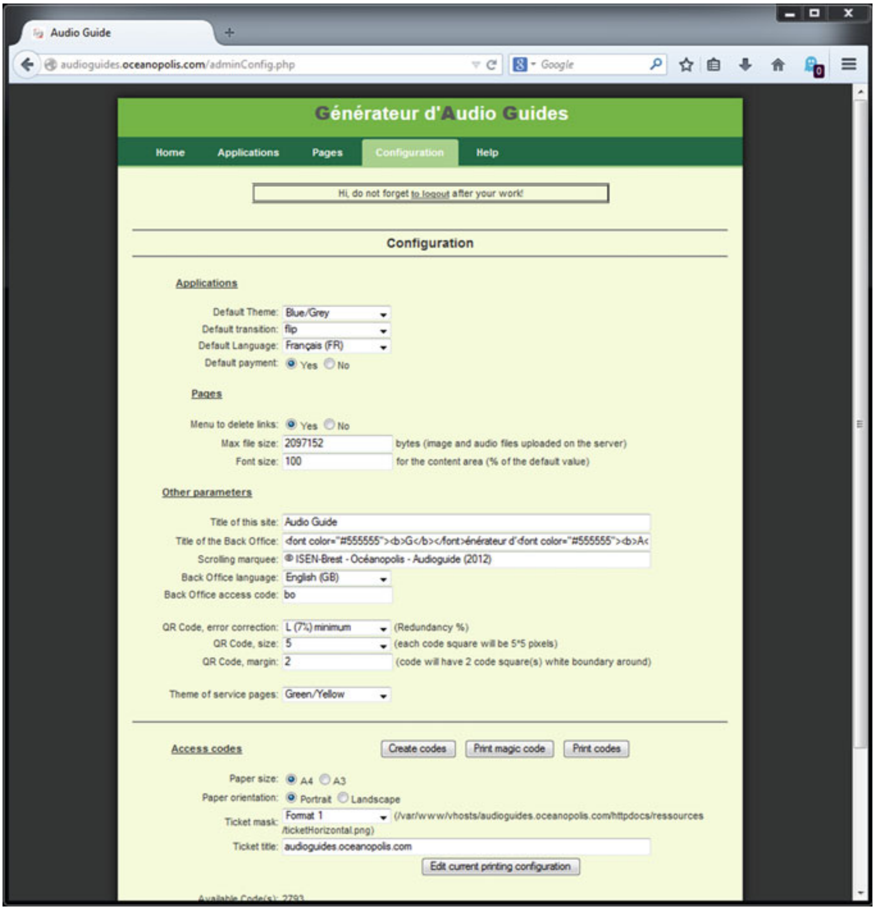


Fig. 8.17 Configuration tab

Fig. 8.18 Sample ticket

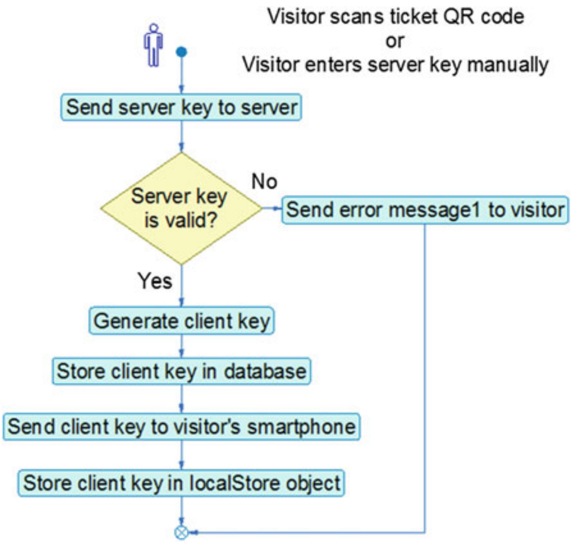


Fig. 8.19 Activity diagram: visitor scans ticket QR code

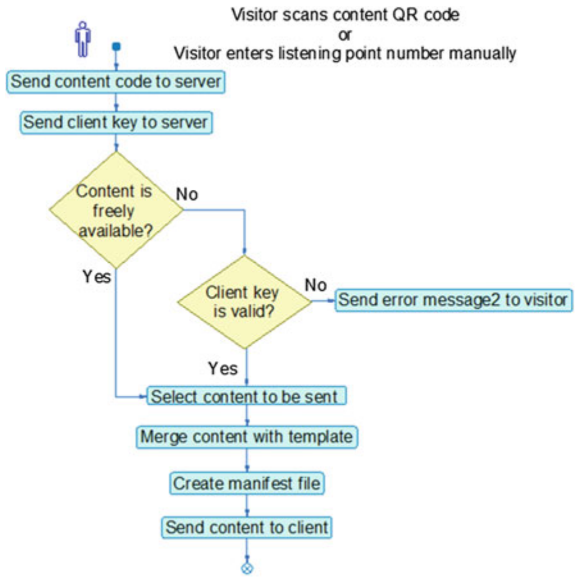


Fig. 8.20 Activity diagram: visitor scans content QR code

8.4.3 Data Loader: From OpenOffice to the Database

The OpenOffice Impress is a multimedia presentation tool equivalent to MS-PowerPoint. Most people know how to handle these tools. Instead of using the authoring tool, the content designer can import an OpenOffice presentation to create

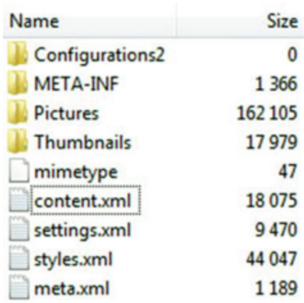


Fig. 8.21 Open document format archive

a new application including group number, language, and pages content. The tool must create the group, if it does not exist.

Open document format. The “open document format” is an open XML-based document file format used in several presentation documents such as OpenOffice [31]. An odp file is a Java archive (Fig. 8.21) containing XML files.

The interesting parts of this archive for a data loader to retrieve information are:

- The “content.xml”: content of the document including pages and frames.
- Pictures: directory containing pictures.

The structure of the “content.xml” file depends on the document type. For presentations, the main XML elements are listed hereafter in Table 8.1.

An image is represented by a <draw:image> element and a media file by a <draw:plugin> element. Both own a “xlink:ref” attribute, which is a reference to the image or media file. For images, it begins with “Pictures”, directory included in the archive, and is followed by the internal file name. Media files are located outside

Table 8.1 Main XML elements of context.xml

Element	Parent element	Description
Office:document-content		Root element
Office:body	Office:document-content	Content of the document
Office:presentation	Office:body	Kind of document
Draw:page	Office:presentation	Element containing all the graphic objects of the page
Draw:frame	Drawn:page	Frame on the slide
Draw:text-box	Drawn:page	Text-box
Draw:image	Drawn:frame	Image
Draw:plugin	Draw:frame	Plugin such as video or sound
Text:p	Elements containing text	Paragraph

the archive, and, therefore, begin with ".." to get out of the archive and is followed by the path to the file. All texts, such as titles or paragraphs, are inside a <text:p> element.

The OpenOffice Impress file structure. In order to retrieve information automatically from the OpenOffice Impress file, this one must respect a few constraints:

- First the document's name is composed of the number of the group and the locale used, such as "360.en_GB.UTF-8.odp".
- Second, the structure of each page follows the template described hereafter (Fig. 8.22).

Each page contains four frames, which are identified by the name attribute to facilitate the data processing ('*i*' is the number of the slide):

- Title: named "*title_i*".
- Textual description: named "*description_i*".
- Image: named "*image_i*".
- Audio description: named "*audio_i*".

For example, text and image from the page shown in Fig. 8.23 are represented as follows in the "content.xml" file.

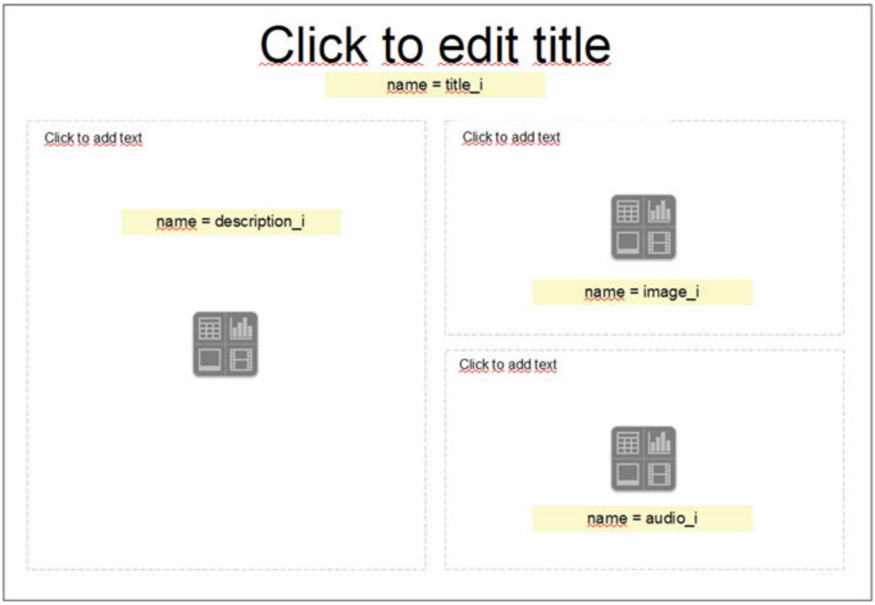


Fig. 8.22 The OpenOffice impress template

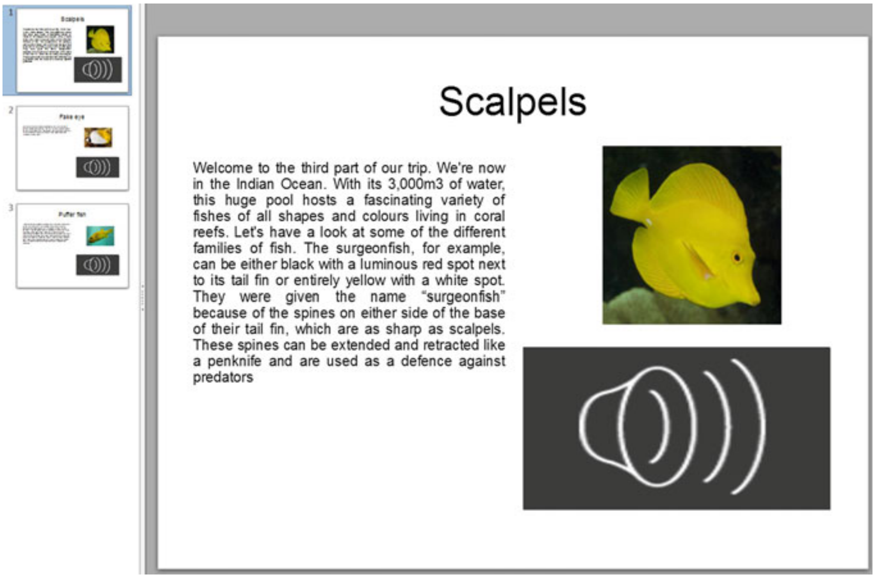


Fig. 8.23 The OpenOffice impress file example named "360.en_GB.UTF-8.odp"

```
<draw:page draw:name="page1" .../>
  ...
  <draw:frame draw:name="description_1" ...>
    <draw:text-box>
      <text:p>
        Welcome to the third part of our trip
        ...
        a defence against predators
      </text:p>
    </draw:text-box>
  </draw:frame>
  ...
  <draw:frame draw:name="image_1" ...>
    <draw:image xlink:href="Pictures/DF4365.jpg" ...>
      <text:p/>
    </draw:image>
  </draw:frame>
  ...
</draw:page>
```

Data Loader. The data loader is composed of three modules in order to simplify software prospective evolutions. The first one is the Man-Machine Interface (MMI) module. This module is available from the "Help" tab of the back office. The page includes an example and a template to help content designer in the presentation creation process; a form to upload the archive file composed of the odp file and an "audio" directory containing the audio files; and text-box to give a feedback to the user on the generation process.

The second one is a parser module. Its purpose is to check the documents included in the archive and to retrieve the information. After decompressing the archive, the software proceeds in verifications on the filename's constraint. It then checks each slide and retrieves information by parsing the "content.xml" file. If everything looks good, all information is kept in variables, which are sent to the integration module, otherwise a feedback message identifying the problem is raised and sent as feedback to the MMI module.

The last one is the integration module. Its aim is to populate the database with the information by creating a new group and/or by adding a new application to a group. A feedback is also sent to the MMI module.

8.4.4 On Client Side

When the visitor buys a ticket and scans the QR code, a test screen (Fig. 8.24) is rendered on their smartphone. This screen has been implemented in order to make sure that:

- The smartphone can read QR codes.
- The web browser can play audio files.
- The web browser is HTML5 compliant, especially for manifest and local storage.

In this screen, the visitor can also choose a favourite language.

In order to get access to audioguides during a tour in the exhibition, the visitor must scan QR codes. These QR codes are deployed within the exhibition next to displays that shows the number of the listening point (Fig. 8.25).

Once the client (i.e. the visitor) is connected to the server, an index page is presented (Fig. 8.26). By clicking on an image, he/she can choose the page they wish to consult. The page is loaded in the browser, and the audio file start to play.

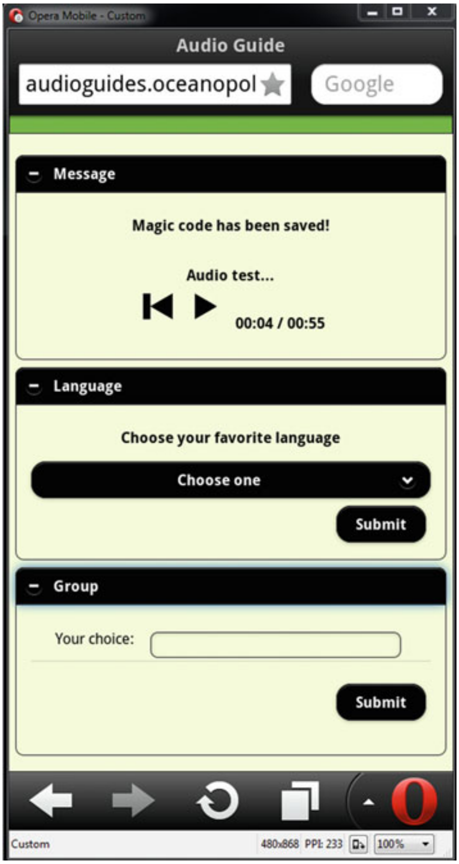
A Navigation tab (Fig. 8.27) enables the visitor to change group and then to get access to any content they are allowed to view. The visitor only has to enter the name of the group or the listening number.

Through the option tab, visitors can choose another language both for contents and user interface. A survey screen is also available (Fig. 8.27). The target is to get feedbacks and comments from visitors about the features of the audioguides.

For the application to work properly, there are only four constraints to be respected:

- Using HTML5 compliant browser (Google Chrome, for example).
- Enabling JavaScript.
- Accepting cookies.
- Not clearing the browser cache.

Fig. 8.24 Test screen



8.4.5 Experimentation

A first prototype with only five groups had been deployed for two weeks for testing purpose. The survey module was activated and we got interesting feedbacks from visitors:

- The QR codes next to displays are insufficiently illuminated for smartphone reader.
- In the darkness, the flash lamp shines the QR code.
- There is no option for manually entering the number of the listening point.
- Tickets already used or expired are distributed at the entrance.
- The WiFi coverage is poor.

According to these feedbacks:

- Special attention was paid to the location of QR codes inside the different pavilions.
- The navigation tab was added to the client software.

Fig. 8.25 Scanning QR codes

- We discovered that some QR code readers were sending a HTTP HEAD Request while we were expecting to receive a HTTP GET Request.
- The WiFi network was fully deployed before going into production.

Some results from the survey are presented hereafter (Figs. 8.28, 8.29 and 8.30).

Most users were satisfied with functionalities that the software offers and its ergonomics. 55 % of the users were unsatisfied with the application response time. This was due to a lack of bandwidth of the WiFi network.

As a result when the application went into production, 60 groups were created and 222 applications were developed for a total amount of 343 pages. Four languages were available. All the contents were developed by people without any experience in Computer Science.

We got 1,992 connections from visitors. Most users were satisfied and especially foreigners, who got contents automatically in their native languages. Today this authoring tool has been tailored for a multi-user context in order to allow each content designer to manage their own material.

To complete the Authoring tool we provide a statistical module that gathers information about visitors on a chosen time period:

- The number of connections we got for each application.
- The language, in which the content was downloaded by a visitor (Table 8.2).
- The operating system, which was used by a visitor (Table 8.3).

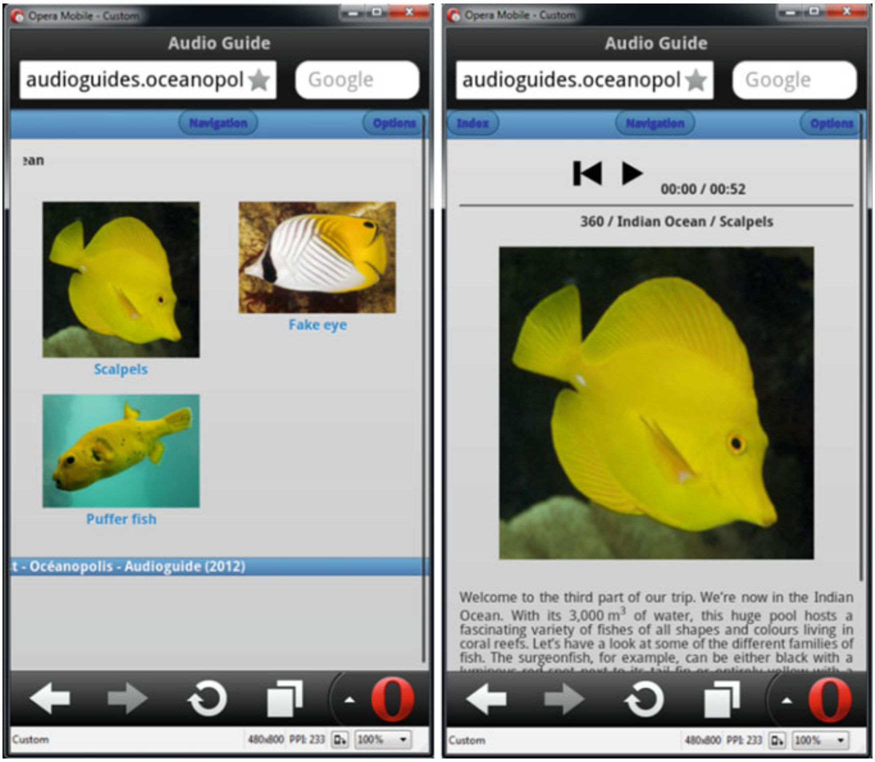


Fig. 8.26 On the visitor's side

8.5 Discussion and Prospects

Using a Bluetooth device in order to push a large amount of data on smartphone does not sound appropriate. This is less flexible to manage, when contents are subject to evolve. If we want to implement large applications, then we have to multiply access points. Therefore, using such a system can quickly become complicated for the visitor.

Nevertheless, we believe in that solution, especially for short contents. Another interest lies in the fact that it does not require any network infrastructure such as WiFi network for example. Also it does not require any skill from any staff except to be able to start and to stop the device.

The web based approach is suitable for huge exhibitions, where there are a lot of topics to be explained to visitors. It requires a network infrastructure such as WiFi. But as the bandwidth for data transfer through smartphones is increasing, the visitor can connect directly to the server.

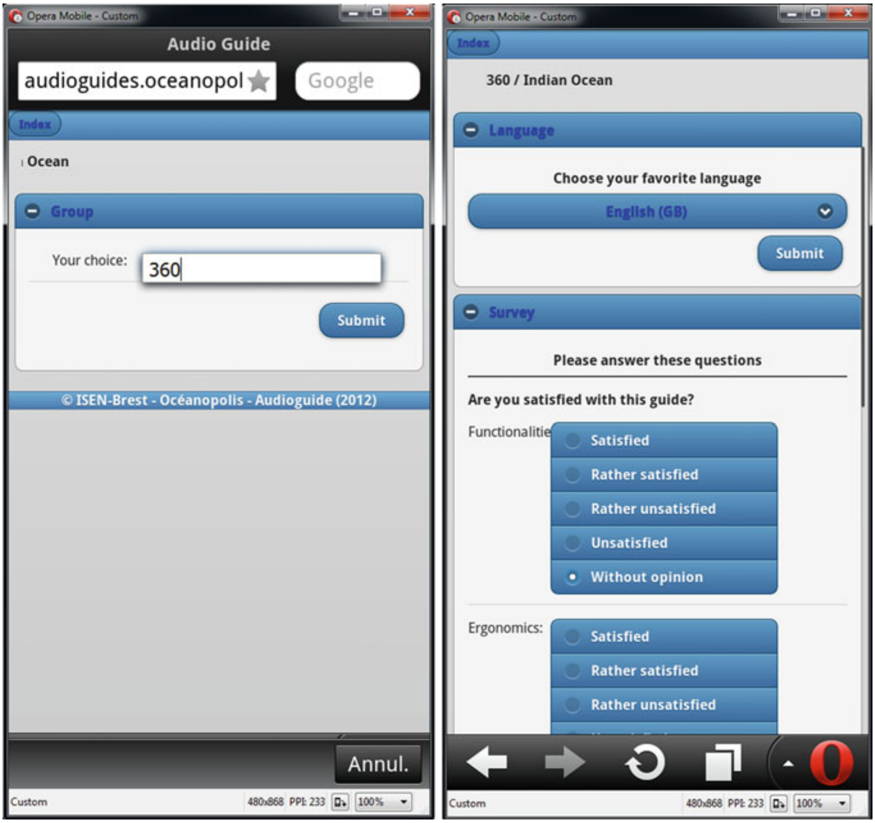
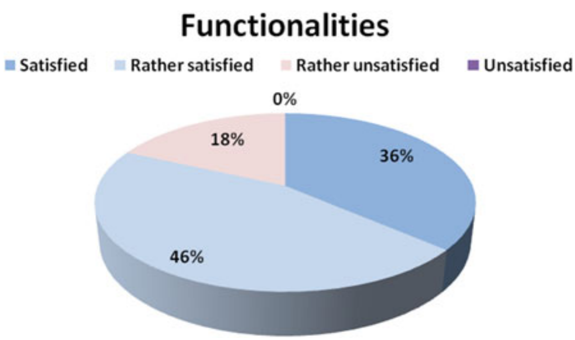


Fig. 8.27 Navigation tab and survey screen

Fig. 8.28 Are you satisfied with the functionalities of this guide?



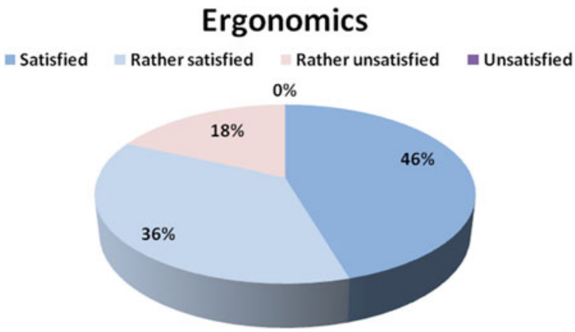


Fig. 8.29 Are you satisfied with the ergonomics of this guide?

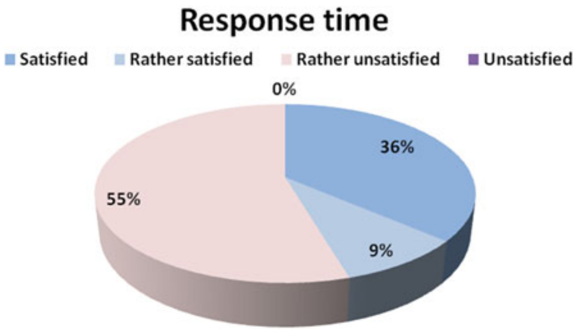


Fig. 8.30 Are you satisfied with the response time of this guide?

Table 8.2 Statistical results for languages

Languages	Percentage
French	67.2
German	22.0
English	6.5
Italian	4.3
Total	100

Table 8.3 Statistical results for operating systems

Operating systems	Percentage
iOS	51.5
Android	45.3
Windows phone	2.2
Blackberry OS	0.8
Others	0.2
Total	100

Concerning future developments of this system, we are thinking about the integration of videos. The videos would enrich the comments. This would also make the visit more interactive. Such integration would be easily developed using the <video> element of HTML5.

Another possibility could be an audio-based navigation to make the system totally hand-free. Also, as we are able to track the visitor during their tour in the exhibition, it would be easy to set up an interactive map showing the busiest routes. This would be of interest for business purpose, for example, to decide, where to install gift shops.

It seems also quite reasonable to imagine the development of Augmented Reality Applications due to new features of HTML5:

- The <canvas> element for 2D drawing.
- The <video> and the <audio> elements for media playback.
- Support for local storage and local database.
- Easy access to smartphone camera and audio.

Another promising approach lies in communicating objects (i.e. the Internet of Things). Some authors have already started working on this topic [32, 33]. Objects could be linked to paintings, artworks, etc. Objects could be implemented on credit-card-sized Linux computer such as BeagleBone. The content that should be delivered to visitors could be located at the object level. They could deliver information to visitors by means of Near Field Communication (NFC), Radio-Frequency IDentification (RFID), or WiFi network.

Objects would be able to recognize visitors: age, preferred language, main interests etc. and then deliver to the visitor a content that should correspond to their profile. The exhibition would be like a sort of ubiquitous environment.

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