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Special theme

Digital Twins

Also in this issue:

Research and Innovation

In-Memory Computing: Towards Energy-Efficient Artificial Intelligence

ERCIM News is the magazine of ERCIM. Published quarterly, it reports on joint actions of the ERCIM partners, and aims to reflect the contribution made by ERCIM to the European Community in Information Technology and Applied Mathematics. Through short articles and news items, it provides a forum for the exchange of information between the institutes and also with the wider scientific community. This issue has a circulation of about 6,000 printed copies and is also available online.

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This section features news about research activities and innovative developments from European research institutes

EVENTS, IN BRIEF

Martina Lindorfer Receives the 2018 Cor Baayen Young Researcher Award

Martina Lindorfer was selected as the winner of the 2018 Cor Baayen Young Researcher Award. The award committee recognises Martina's impressive achievements and outstanding quality of her research in the field of systems security, especially the analysis of malicious software and mobile operating system vulnerabilities. Martina Lindorfer is a tenure-track assistant professor in the Security & Privacy group at TU Wien. Until recently, she was a postdoctoral researcher in the Computer Security Group (SecLab) at the University of California, Santa Barbara, US. She received her PhD from TU Wien, where she was working at the International Secure Systems Lab (iSecLab). During her PhD, she was also a researcher with SBA Research, the largest research centre in Austria which exclusively addresses information security, where she was advised by Edgar Weippl, SBA Research's research director.

Malware is the basis of many forms of cybercrime. Motivated by financial gains, malware authors are constantly evolving their code to increase their profit by evading security defences and developing new monetisation techniques. Manual analysis of an ever-increasing number of malware samples is infeasible and developing effective and efficient automated analysis methods is technically challenging because source code for these types of programs is not available, and malware binaries are highly obfuscated and designed to foil any type of analysis. In her work, Martina developed novel techniques to address the challenges faced by large-scale dynamic analysis of malware samples due to the arms race against malware authors. Martina has also developed novel analysis techniques for detecting and mitigating privacy leaks in mobile apps.

During her postdoctoral work she expanded her research to the exploitation of the Rowhammer bug, which is a low-level vulnerability in operating systems and hardware that can be exploited by malicious apps, and defences against the resulting attacks. In her resulting work—Drammer: Deterministic Rowhammer Attacks on Mobile Platforms—she demonstrated for the first time that this vulnerability also affects mobile devices, and that it can be exploited deterministically, without having to rely on software vulnerabilities or special operating system services. In follow-up work, "GuardION," she also demonstrated how Google's patches against Drammer are incomplete, and proposed a better defence based on memory isolation, which is expected to be integrated in future Android versions.

Her research on Drammer received a number of awards: the Best Paper Award at the CSAW Applied Research Competition, the Best Dutch Cyber Security Research Paper (DCSRP), as well as a Pwnie award for Best Privilege Escalation Bug and a Pwnie nomination for Most Innovative

Martina Lindorfer receives the Cor Baayen Young Researcher Award from ERCIM President Jos Baeten.

Research at Black Hat 2017. Drammer was also recognised by the Android Security Rewards Program, and has prompted Google to issue a number of patches. She developed a popular Android app to allow users to verify whether their devices are vulnerable.

Beyond academic publications, her work has had a significant impact on the research community and society in general. Fellow researchers, malware analysts in industry, as well as individuals who were interested in the security and privacy implications of mobile apps have frequently used her dynamic Android app analysis sandbox "Andrubis." It was used by law enforcement to analyse suspicious apps found on seized devices, and featured in TV news programmes. The techniques used by Andrubis and her follow-up work are now being widely used in industry: they are integrated in anti-virus solutions, being sold as stand-alone products and services to secure enterprises, and used by app market operators, such as Google, to vet apps before they are being published and made available to the general public.

Her work on privacy leak detection with ReCon, which is a service for detecting and blocking private information leaks in mobile app traffic, received a grant from the Data Transparency Lab. ReCon and its follow-up work are also publicly available to end users. Her analysis on the longitudinal privacy behaviour of mobile apps serves as a guideline for users to decide whether to install or update an app, based on their personal privacy preferences. Her work has also raised the interest of regulatory agencies, such as the Federal Trade Commission (FTC), and telecom providers, who are interested in adopting her techniques to protect consumers' privacy. ReCon was also featured in the short film documentary "Harvest" to raise awareness of mobile privacy issues. The film was shown at several prestigious film festivals, including Aspen Shortsfest, HotDocs, Seattle International Film Festival, and the Rooftop Films summer series in New York.

The Cor Baayen Young Researcher Award is awarded each year to a promising young researcher in computer science or applied mathematics. The award carries a prize of € 5000.

https://www.ercim.eu/human-capital/cor-baayen-award

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Bruno Sportisse Appointed CEO of Inria and President of ERCIM EEIG

Bruno Sportisse was appointed Chairman and CEO of Inria on 27 June 2018 by a decree of the President of the French Republic. He replaces François Sillion who has been acting as Inria's Chairman since 22 January 2018.

Bruno Sportisse is a graduate of the École Polytechnique and chief engineer of the Corps des Ponts et Chaussées. He also holds a PhD in applied mathematics. His entire scientific career has been with or within Inria where he was Director of Technology Transfer and Innovation from 2008 to 2012.

In 2012, he was appointed as the digital and innovation advisor to the French Minister of Higher Education and Research, Geneviève Fioraso, then, in 2013, as Deputy Chief of staff to the French Minister for Digital Economy, SMEs and innovation, Fleur Pellerin. Notably, he initiated and led the interministerial programme "New Deal for Innovation", including the launch of the French Tech Initiative.

In 2014, Bruno Sportisse became the Executive Vice President of Thuasne, a mid-sized MedTech company, where he initiated the digital transformation of the company. In 2016, he started an entrepreneurial adventure that led to the creation of Skopai, a FinTech startup from the University of Grenoble-Alpes, combining artificial intelligence and natural language processing.

In 2018, he was given the task by the French Ministers Bruno Le Maire (Economy), Florence Parly (Defense), Frédérique Vidal (Higher Education, Research and Innovation) and Mounir Mahjoubi (Digital) to propose a design and implementation of a European Agency for Breakthrough Innovation in conjunction with the creation of the European Innovation Council (EIC) within the next European R&D framework programme.

Bruno Sportisse succeeds Antoine Petit as Inria's representative on the ERCIM EEIG Board of Directors. He was nominated President of ERCIM EEIG by the ERCIM EEIG Board of Directors on 9 October 2018 in Gothenburg for a two-year term. ERCIM EEIG, the European Economic Interest Grouping, is responsible for managing the ERCIM Office and hosting the W3C European Host.

VRE4EIC Reference Architecture and Software Components Available

The ERCIM-managed Horizon 2020 project "VRE4EIC" has successfully developed a reference architecture and software components for Virtual Research Environments (VREs).

e-VRE (enhanced VRE) is the result of the European research project VRE4EIC. e-VRE is designed to build or enhance e-Research Infrastructures (e-RIs). e-VRE provides a comfortable homogeneous interface for researches and developers by virtualising access to the heterogeneous datasets, software services and resources of the e-RIs. On top of this, it also supports collaboration and communication between users/researchers.

The potential of e-VRE is demonstrated by the European Plate Observing System (EPOS) and ENVRI+, a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks. Both EPOS and ENVRI+ are represented in the project, themselves supported by e-Infrastructures such as GEANT, EUDAT, PRACE, EGI, OpenAIRE.

VRE4EIC provides a superset canonical rich catalog into which information from the distributed heterogeneous e-RI catalogs is imported via convertors. It thus provides a homogeneous view over the heterogeneous metadata describing the assets and thus automates findability and accessibility. Access to the catalog is offered via the Metadata Manager component of the reference architecture, encapsulating all operations on the descriptions held in the catalog. The Metadata Manager was included in the architecture of EPOS, enhancing EPOS' interoperability level.

The current state of the art has some interoperability and re-use among research assets but this is usually restricted to a particular domain where local metadata standards are utilised. However, the interoperation usually requires considerable human effort and rarely is (even partially) automated. The VRE4EIC catalog will allow homogeneous access across the heterogeneous metadata provided, and thus —progressively—interoperability and re-usability.

The project has produced a series of video tutorials about VREs in general, and the VRE4EIC reference architecture and component services in particular. The e-VRE source code is available on GitHub.

https://www.vre4eic.eu/
https://www.vre4eic.eu/tutorials
https://github.com/vre4eic

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Introduction to the special theme

Digital Twins

by Edgar Weippl (SBA) and Benjamin Sanderse (CWI)

This special issue addresses the current state of digital twin research, illustrating the many facets of this growing scientific field. The contributions collected here give insight in ongoing projects and allow for a glimpse into the future of digital twin technology.

In engineering, the use of models to represent reality might be as old as the profession itself. Most famously, NASA has built so-called "twins" of its spacecrafts since the early Apollo program: in 1970 Mission Control engineers improvised a device (nicknamed "the mailbox") which was replicated by the Apollo 13 crew in order to solve one of the technical problems in their return to earth. Recently, the explosion in terms of data, algorithms, and computational power has allowed the creation of a new "twin" concept: Digital Twins.

A digital twin (sometimes also "digital shadow") is a digital replica of real-world devices, processes or even persons. The technology draws on domains like machine learning, artificial intelligence and software analytics to provide a dynamic digital representation of its physical counterpart. Thereby, it uses data provided for example by Internet of Things (IoT) sensors as well as information coming from past machine usage and human domain experts. Currently mainly used in the context of Industry 4.0, digital twins provide models and simulations of, e.g., wind turbines or aircraft engines. Large companies like GE, Siemens, Shell and SAP are using this technology to create virtual models to monitor and diagnose their physical assets and systems, optimise operation and maintenance and calculate future performance [1]. Especially in the context of cyber-physical systems (CPS), digital twins are of increasing importance.

The general idea is to create a digital partner throughout the lifecycle of all entities involved; digital twins are created entirely based on the specifications of their physical counterpart, whereby they document all its changes and developments. In order to do so, digital twins require data obtained from a system's or device's history, the experts working in the domain and even data from other (third party) entities, processes, and systems. Thus, a digital twin is able to provide information about and current status reports of its physical counterpart. Once set up, digital twins are used in manifold ways: a tool to handle data (e.g. generated by IoT devices), a model to run calculations and scenarios to reduce time and costs of product development and/or installation of complex systems, or a tool to provide a constant overview of systems which are often spatially distributed and used by multiple parties. Lastly, given that digital twins may easily be run in isolated environments, they can be meticulously analysed (e.g., regarding security measures) without disrupting operational systems. In the future, they will be joined with further technologies like augmented reality or AI capabilities, facilitating looking inside the digital twin, holding the promise to make checking the actual devices or production processes unnecessary [1].

The progress in developing digital twins is, amongst others, made possible through many important ongoing scientific research achievements in several fields in the mathematics and computer science community, such as: data assimilation, model order reduction, data-driven modelling and machine learning, high-performance computing for real-time simulation, visualization, etc. The articles in this special issue show that indeed much progress has been made, but that at the same time new research and new algorithms are imperative to make real-time simulation, data handling, and optimization of complex systems possible.

The industrial drive behind many digital twins is apparent in several articles in this issue. For example, Ponsard et al. (page9) discuss the case of a steel factory and demonstrate how a digital twin may be used for decision making even if the connection with the physical counterpart should partially or temporarily fail. Verriet et al. (page 10) work with major industry players such as Philips Lighting, to develop an open architecture solution for connected lighting systems. The digital twin representing this system includes the environment in which it will be operating as well as the interactions with other systems and is used for validation and testing before actual installation. Strohmeier et al. (page 12) present a messaging system which is the foundation for digital twins of industrial assets; it collects, monitors and analyses life cycle data with the goal of improving maintenance operations and long-term asset strategies. Further industrial applications are found in the articles of van Kruijsdijk (Shell), page 14, and Boschert and Rosen (Siemens).

Next to a clear industrial interest there is an important societal component in digital twin research. For example, Závodsky et al. (page 18) work on developing human digital twins in order to provide optimal, personalized medical treatment of patients.

In many articles, security and safety play a key role in digital twin development. Boschert and Rosen (page 8) look at transport infrastructure, in particular railway switches whose maintenance is essential to guarantee safety. By using a combination of measurement data and physics-based simulations they develop a digital twin which enables to identify failures in the physical components before they become critical. Eckhart and Ekelhart (page 22) use virtual replicas of cyber-physical systems (CPSs) to monitor, visualize and predict the behaviour of CPSs. Their goal is to demonstrate how digital twins can increase the security of CPSs throughout their entire lifecycle. The authors have developed an experimental prototype and explicitly distinguish in their approach "CPS Twinning" in simulation mode (i.e., the digital twin runs independent from their physical counterparts) from replication mode (i.e., the twin mirrors the state of the physical device). Tauber and Schmittner (page 23) look at security and safety evaluation in Industry 4.0 use cases. Given that system properties like security and safety are difficult to measure (as opposed to physical features), the authors investigated the modelling of such dependencies in relation to transparency and self-adaptability. Here, digital twins are a means to organise and manage all the data generated by IoT, since other models currently used are too static to accurately represent the dynamic and changeable nature of IoT devices. The authors also introduce the aspect of using digital twins in case of legal issues.

Lastly, the topic of security and safety is addressed by Damjanovic-Behrendt (page 25), who turns her attention on the Smart Automotive sector where strategic alliances between manufacturers make it difficult for researchers to gain access. Therefore, the collaborators in the project IoT4CPS are developing an open source digital twin prototype using machine learning for behavioural analysis and to predict security, privacy and safety measures.

Overall, the articles of this issue paint a detailed picture how industrial applications and academic research of digital twins are currently evolving and diversifying. The novelty of the topic of digital twins makes that many research activities are 'work-in-progress'. In the coming years, we expect a flourishing research field in which mathematicians and computer scientists are working together to address important societal and industrial challenges.

Reference:

[1] Digital twins – rise of the digital twin in Industrial IoT and Industry 4.0 https://www.i-scoop.eu/internet-of-things-guide/industrial-internet-things-iiot-saving-costs-innovation/digital-twins/

Recommended Reading:

- Thomas H.-J. Uhlemann, Christian Lehmann, Rolf Steinhilper, The Digital Twin: Realizing the Cyber-Physical Production System for Industry 4.0 (2017), https://doi.org/10.1016/j.procir.2016.11.152
- Roland Rosen, Georg von Wichert, George Lo, Kurt D. Bettenhausen, About The Importance of Autonomy and Digital Twins for the Future of Manufacturing (2015), https://doi.org/10.1016/j.ifacol.2015.06.141
- Digital twin technology and simulation: benefits, usage and predictions 2018, https://www.i-scoop.eu/digital-twin-technology-benefits-usage-predictions/

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Digital Twin: a Second Life for Engineering Models

by Stefan Boschert and Roland Rosen (Siemens AG)

Railroad switches, also called turnouts or points, are a key element of the rail network infrastructure. They are distributed all over the network and their maintenance is crucial to guarantee safety and undisturbed operation. Within a railway network, the turnouts are responsible for a high amount of the operational costs as monitoring and maintenance is mainly manual. Using a combination of measurement data and physics-based simulations – a typical Digital Twin application – has a high potential to identify failures before they become critical. Defining a general methodology to derive such solutions which make use of all the relevant information created along the lifecycle is the subject of our current research.

Recently, the Digital Twin has become very popular, appearing as one of Gartner top10 technical trends for 2017 and 2018 [1]. Here it is defined (in an IoT context) as a digital representation of a real-world entity. The Digital Twin collects all information on the state and usage of physical entities and links it to information on the state of counterparts and provides support reaction to changes, thus adding value to the usage of the entity.

The exclusive focus on the data-mining aspect of the Digital Twin neglects an essential aspect of the original idea of having a digital companion throughout the lifecycle of all entities. The general concept behind the Digital Twin dates back to Michael Grieves' 2002 presentation in which he presented a "Conceptual Ideal for PLM". This Ideal contained all important elements of the Digital Twin: real space, virtual space, information flow from virtual space to real space and virtual sub-spaces [2]. The term "twins" seemed appropriate given the duality of real space and virtual space and the ability to use whichever is most suitable for a given problem. NASA had already used such an analogy during the early Apollo program to reference duplicate space vessels that remained on earth and were used to mirror the actual flight conditions.

The terms Digital Twin prototypes (DTP) and Digital Twin instances (DTI) were introduced to distinguish the different character and purpose of the Digital Twin [2]. In the early lifecycle phases, the DT consists mainly of artifacts used to optimise the product functionality. The digital models are used to check design alternatives and to test product functionalities against its requirements using virtual prototypes (the Digital Twin prototype). This approach greatly contributes to reduce time and costs during product development. On the other hand, the DTI emphasises the aspect that with each individual physical entity, (digital) information is also collected through the whole lifecycle. This need not be limited to sensor and operation data, but may also include information from its production (e.g. supplier or production line). With the rise of sensors everywhere, a vast amount of data is available to be linked to the DTI. Also, as the DTP focuses on the general behaviour of the entity, it can be seen as a common part of each DTI and can be exploited to create solutions.

The models included in the DTP are usually created for very specific design questions. Therefore, many different models tend to be available for the same component, each representing a different design question on an appropriate model granularity. Modern PLM systems help to archive and to keep track of these models. However, a vast amount of models and even more resulting data are created during the engineering phase, the sum of which cannot be maintained; a first decision on what models and data are preserved has to be taken. This makes it difficult to deduce new models for novel application fields occurring in the operation phase, as information on the limitations and

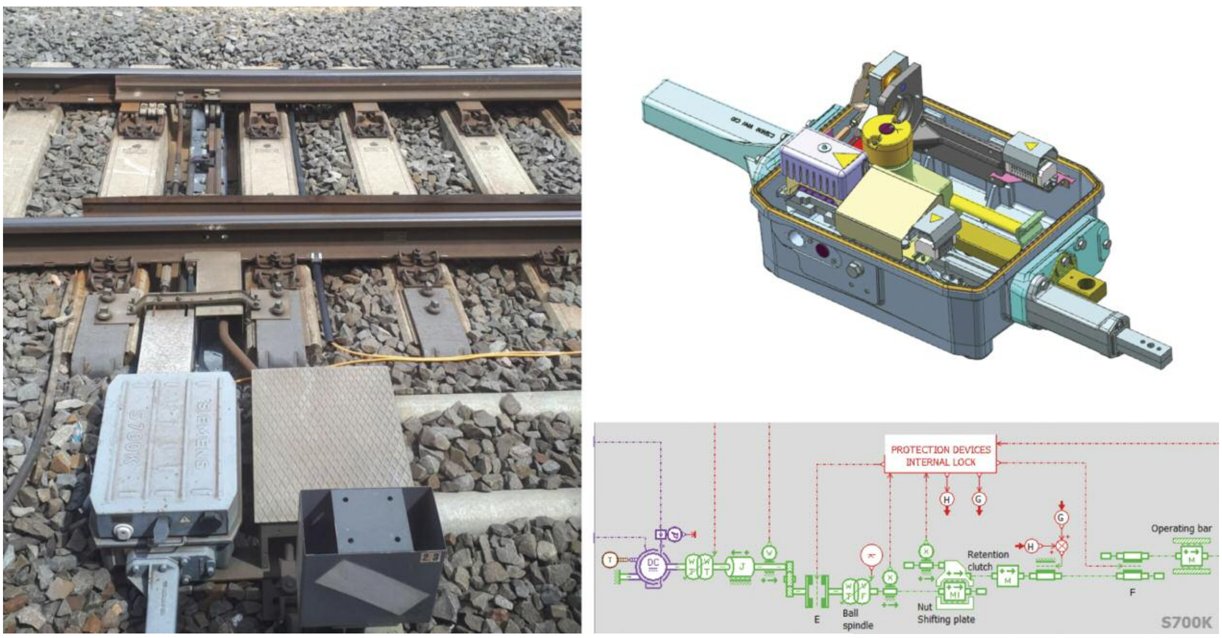

Figure 1: Point machine (left) and simulation models of different granularity (right).

assumptions and underlying ideas on the existing models are probably no longer available. On the other side, in many cases it is already foreseeable which questions will be asked during the operation phase to the product, or in other words, which functionalities the Digital Twin of the product has to provide for the operation phase. Therefore, it is sensible to design these Digital Twin features in parallel with the product as shown in the example of the Digital Twin of a point machine used for failure identification [3].

The interactions between railway switch and its drive (point machine) are complex. Many different physics-based models are used to verify that the design guarantees a safe operation during the whole lifetime. During the operation of the point machine in the field, the actual conditions and possible looming failures are of interest for the operator. The detailed models used to engineer the system already contain most of the ingredients to create the tools to handle these questions. Therefore, these models are enhanced to be able to simulate possible failures during the time when the models are created initially. To this end, they have to be simplified (e.g. by deducing 1D models from complex 3D simulations) and to be configurable for individual situations. This requires only a little extra effort compared to the complete re-modelling necessary if the models were to be created during operation phase. It is essential that these models are treated as an integral part of the product so that they too are maintained to remain operable (e.g. get necessary software updates). During the instantiation (i.e. the actual dispatch of the point machine on the track) some configuration parameters – specific to the current configuration e.g. turnout-radius – have to be set in the model. The DTP is now individualised to become the specific DTI for this turnout. By using this simulation model and comparing its results to current sensor data from the track, looming failures can not only be detected but also their root-cause can be identified and so tailor-made maintenance measures can be deduced. The engineering models that required considerable resources for their initial creation thus have a second use. And the availability of the railroad tracks and thus the riding comfort is significantly increased.

References:

[1] "Gartner top 10 Strategic Technology Trends for 2017", received from https://kwz.me/htG
[2] M. Grieves, J. Vickers: "Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems", in F.J. Kahlen et.al.: "Transdisciplinary Perspectives on Complex Systems", Springer 2017
[3] S. Boschert, R. Rosen, C. Heinrich: "Next Generation Digital Twin", in: I. Horvath et al (Eds.) Proc. TMCE 2018, S.209-218.

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Accurate Reasoning Using Imperfect Digital Twins: A Steel Industry Case Study

by Christophe Ponsard, Renaud De Landtsheer and Birgit Palm (CETIC)

Reflecting the state of a complex physical asset or process into its digital twin cannot be a perfect process. However, accurate reasoning must stay possible on a digital twin even in case of partial or temporary degradation of its connection with its physical counterpart. In the scope of an Industry 4.0 project, we are investigating how to deal with such a challenge for the optimised operation of a steel factory.

The digital twin concept can be defined, fundamentally, as "an evolving digital profile of the historical and current behaviour of a physical object or process that helps optimise business performance" [1]. The concept emerged from the growing digitalisation in many sectors like Industry 4.0 together with the big data technologies enabling the exploitation of the massive amount of data being generated. However, there are risks associated with the blind use of technology, such as the inability to know how close to reality the digital twin is at a given time, making it difficult to know what can be predicted by using it as a dynamically evolving model of reality.

In order to tackle this problem in the case of partially defined workflow, we developed an approach mixing both a flexible workflow model including physical constraints and a data-driven process mining based on various types of field sensors. The aim of such a twin is to be able to detect how well/optimally the process is behaving and in case of deviation to explore a way to restore normal operation with minimal impact.

Our context is the TrackOpt project aiming at improving the tracking and optimisation of steel making processes [L1]. The project involves both specialists in steel (the German BFI steel research centre and the Ferriere Nord company in Italy) and in optimisation (CETIC in Belgium and Scuola superiore Sant'Anna in Italy). Figure 1 shows an exemplary steel making process organised as a pipe of specific processing steps. A number of ladles are moving from one processing station to the next either using a crane or a ladle car (on rails). A number of waiting/swapping positions are also possible between stations. Of course many ladles are engaged simultaneously in order to ensure continuous casting.

Building a digital twin combines a global workflow model with known constraints such as typical durations due to physical constraints (e.g. for melting, casting) and a data collection process to gather key information about the ladle position using weight sensors and manual encoding of identification.

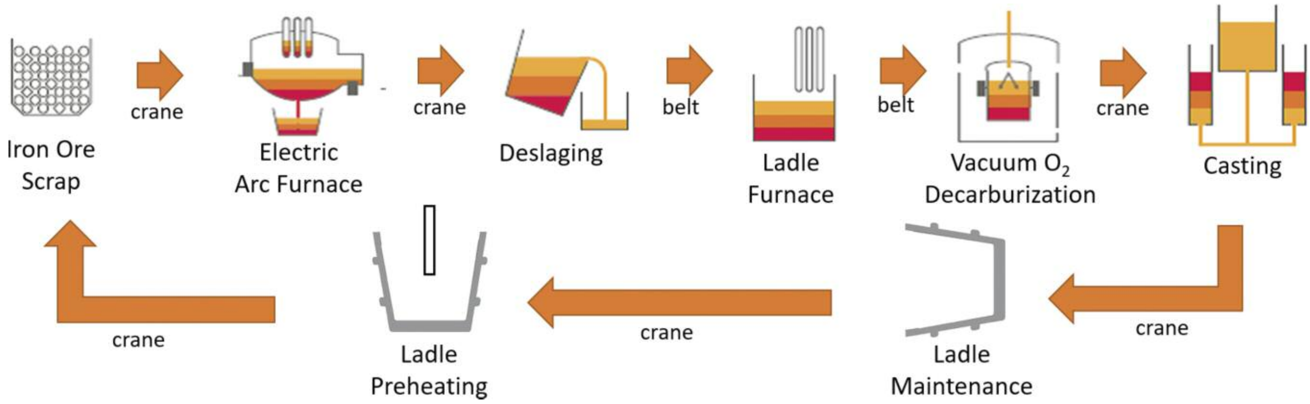

Figure 1: Typical steel making process using moving ladles.

Increasingly automated recognition of ladle is also used and is one of the aims in the project TrackOpt. However the information might be partial or wrong, e.g. in case of encoding error, recognition failure (due to harsh environment/sensor malfunction). In this case, uncertainty is introduced into the digital twin which means the real process could be in a collection of alternative states resulting somehow in a multiplicity of digital clone variants. Accurate reasoning can, however, be maintained by applying the workflow model to each possible twin variant used as model, in a way close to the experimental twins approach [2]. In addition, we also apply a reconciliation process based on the available information which allows us to reduce the variant scope to the right alternative until the digital twin is unique and precise again. The exact meaning of accuracy can be defined based on a goal-based analysis of the required properties together with an audit of the system monitorability also coping with the occurrence of risks impacting it [3]. This processing could also cope with the occurrence of process deviations, like when a ladle needs a repair between stations and needs to be optimally reinserted to preserve the steel quality. In this case, the system can explore possible schedules and propose a corrective one even based on partial knowledge of the whole system. We plan to implement such an engine based on the OscaR optimisation library and more specifically the constraint-based local search engine [L2].

References:

[1] A. Parrott, L. Warshaw: "Industry 4.0 and the digital twin manufacturing meets its match", Deloitte, 2017.
[2] M. Schluse, L. Atorf, J. Rossmann: "Experimentable digital twins for model-based systems engineering and simulation-based development", IEEE SysCon, Montreal, QC, 2017.
[3] A. van Lamsweerde: "Requirements Engineering: From System Goals to UML Models to Software Specifications",.Wiley, 2009.

Links:

[L1] https://www.cetic.be/TrackOpt
[L2] https://bitbucket.org/oscarlib/oscar

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Using Digital Twins to Create and Manage Complex Distributed Control Systems

by Jacques Verriet, Jack Sleuters and Richard Doornbos (TNO-ESI)

Modern smart systems are incredibly complicated. Building a digital twin of the system allows engineers to ensure that it works correctly and root out many problems before it is installed.

The internet of things promises a connected world where we can access and control every object around us. But actually building these interconnected systems is a massive challenge. As part of the OpenAIS project [L1], sponsored by the EU Horizon 2020 Programme, ESI (TNO) [L2] along with the TU/e and major industry players including Philips Lighting, developed an open architecture solution for connected lighting systems. The focus for ESI was to develop the tools needed to build digital twins of these complicated systems that would allow them to be validated and tested before being installed and commissioned.

Components of a Digital Twin

When building a digital twin of a system, there is more to consider than the system itself. The environment in which the system will be installed also needs to be modelled, along with interactions with people or other systems. And it needs to be verified against system requirements and tested with user scenarios to ensure it works as intended.

Therefore, to build a useful and accurate digital twin, in addition to specifying the system itself, one needs to define the environment, and create rules and tools to validate it. For each area (environment, system, and validation), ESI developed Domain Specific Languages (DSLs) to define and build the virtual components of the system, the environment, operating requirements, and test scenarios [1]. In total, eight different DSLs were created (see Figure 1).

Domain

The domain is the environment in which the system will operate. Two languages were developed for creating a customisable domain. The Structure DSL defines topology elements and their containment such as "floor" and "office" and that an "office" is part of a "floor". In the case of the OpenAIS project this was used to define the layout of the fifth floor of the "Witte Dame" (White Lady) building in Eindhoven. The Event DSL is used to specify events in the system such as "occupancy" (when a sensor detects someone in a room) and "light level" (the lights should be on when someone is present or off when the room is empty).

System

For the actual system itself, three domain-specific languages were developed: Topology, Behavior and Control. The Topology DSL defines the structure of the system, the Behavior DSL defines what the system should do, and the Control DSL defines how it should work. Together, these three languages provide a complete system specification.

Using the Domain and System languages, the OpenAIS team was able to develop a complete digital twin of the top floor of the Witte Dame and the planned new lighting system. The next step was to validate and test the model.

Validating the Digital Twin

While the first two sets of languages define the domain and system, the Validation DSLs focus more on the system requirements. Three languages were developed for this area covering: Requirements, Scenario and Experiment.

The Requirement DSL covers the system requirements. The Scenario DSL specifies the behaviour of the system environment. And finally, the Experiment DSL combines the information of all languages.

Using the model transformations from the Experiment DSL, the team was able to automatically generate an interactive simulation and a model checking model. This enabled the team to see how the system worked under the different scenarios. The Requirement DSL was used to generate requirement monitors that were used to automatically identify potential problems and errors.

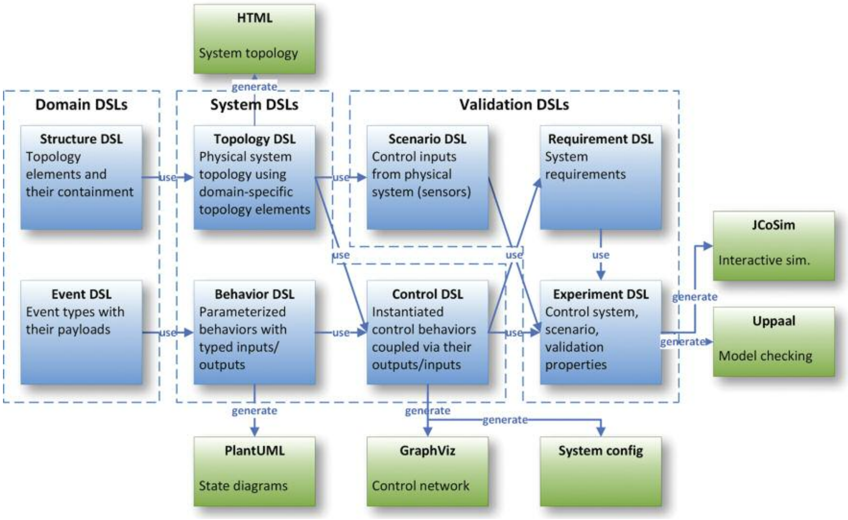

Figure 1: Domain-specific languages (DSLs) and model transformations.

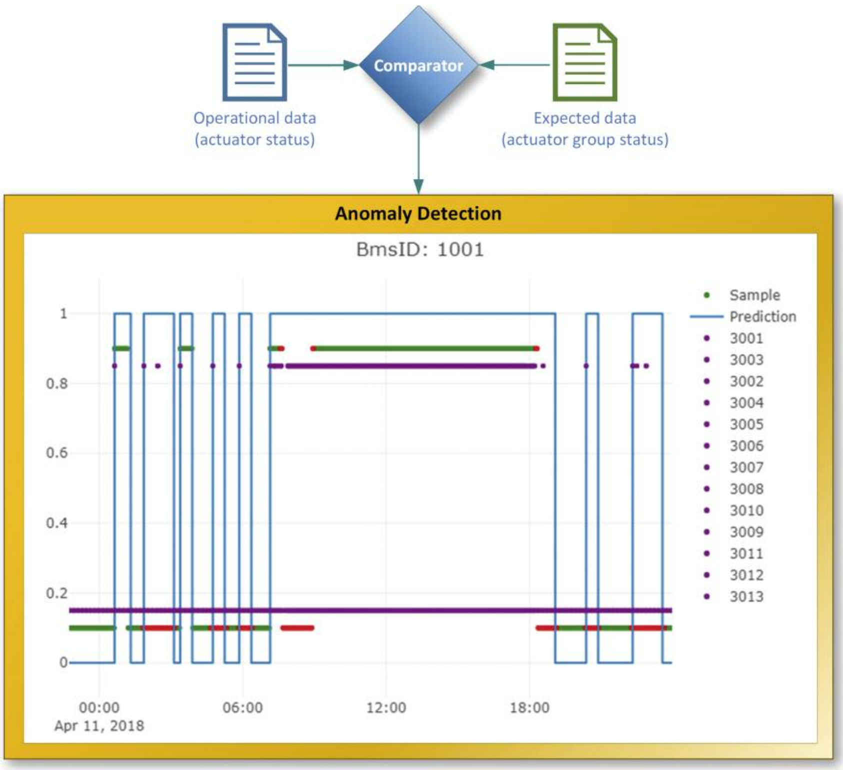

Figure 2: Digital twin takes real sensor data (purple) as input to generate reference actuator data. Operational actuator data is compared with the reference actuator data (blue) to detect an anomaly (red).

From Virtual to Actual

Having built and tested the complete virtual system, the next step was to build it for real. The pilot project at the Witte Dame contained some 400 luminaires with embedded sensors. This lighting control system is based on IoT-standards and frameworks, with IP connection to the end node. It combines wired and wireless devices from multiple vendors in a single system connected through a standard IT-network with commercial off-the-shelve IT components.

Using the Digital Twin to Solve Problems with the Real System

For the Witte Dame project, the digital twin was primarily used for development and testing of the system before installation. However, there are many benefits to be had by using digital twins for debugging problems during installa-

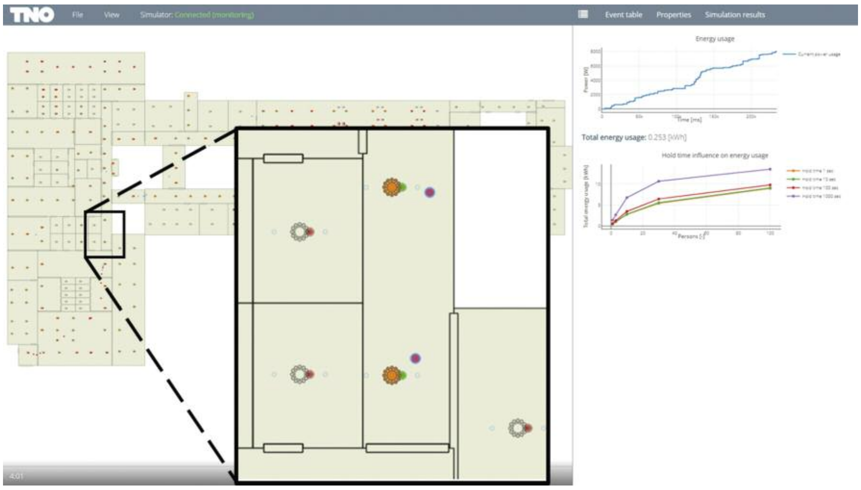

Figure 3: Visualisation of the digital twin showing an interactive simulation where sensors can be triggered manually and the corresponding actuator behaviour is shown. Graphs showing the power usage of the system are plotted.

tion, and throughout the lifetime of the installation to find the real root cause of problems from equipment failures to human errors.

To address this, ESI applied a root cause analysis methodology that combines manual and automatic analysis to solve issues with the system during installation, commissioning, and operation. The methodology comprises four phases: collect, detect, analyse, and resolve.

In the collect phase, data that is relevant to detecting failures, is collected. This can be manual inspection reports and logs, or errors automatically reported by the system. In the detect phase, collected actuator data is compared against the digital twin generated actuator data (see Figure 2): differences indicate anomalies. Now that an error has been detected, the next step is to determine exactly which error has occurred.

In the analyse phase, the error is automatically analysed in detail. Expert knowledge in the form of FMEA and HAZOP studies, is used to find the root-cause of the error. The approach taken resembles the Fishbone (Ishikawa) method.

In the Resolve phase, the RCA system provides a list of steps that the user needs to take to solve the problem. This can be used to provide clear instructions to the installer or maintenance personnel, who typically do not have expert knowledge of the system.

Successfully Tested and Ready for Action

Demonstrated at the OpenAIS Symposium in May 2018, this project showed that the DSLs can be used to create accurate digital twins for development and testing of complex systems and that these models can then be used to automatically detect and determine the root cause of issues in the real system.

Link:
[L1] OpenAIS website: http://www.openais.eu/
[L2] ESI website: http://www.esi.nl/

Reference:
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i-Maintenance: A Digital Twin for Smart Maintenance

by Felix Strohmeier, Christoph Schranz and Georg Güntner (Salzburg Research)

The i-Maintenance toolset is a messaging system that constitutes the technical foundation for digital twins of industrial assets by collecting, monitoring and analysing life cycle data. The messaging solution can be used in an innovative way to set up a prototypical digital twin of a production asset by integrating maintenance management, condition monitoring, IoT and predictive analytics solutions.

In a digitised production environment, maintenance operations and long-term asset strategies can be considerably improved by having precise knowledge about the current state of machines and other equipment in combination with historical data of the same. Increasing the overall equipment effectiveness (OEE) requires a reliable and scalable flow of lifecycle and status information generated throughout the production process.

The work described in this article is carried out in the innovation network "i-Maintenance": In this project, we develop a toolbox consisting of methods and tools supporting the digital transformation of industrial maintenance activities. One of the proposed technical tools, the i-Maintenance toolset, provides a messaging solution and a set of adapters for integrating sensor/actuator systems and other software components in a maintenance scenario. The goal is to create a comprehensive digital twin of an industrial asset to gain insights into the status of all components related to the production and maintenance process and to enable a seamless communication between the proprietary tools provided by our project partners.

A proof-of-concept demonstrator is implemented based on the architecture shown in Figure 1. In the laboratory setting at Salzburg Research, a 3D-printer takes the role of a production asset. Maintenance tasks are managed by means of a Computerised Maintenance Management Software (CMMS). The 3D-printer has been equipped with external sensors, a video camera and a condition monitoring system. Data collected from the printer and its environment is used to predict maintenance tasks: Cleaning the hot end ("the nozzle") is required at irregular intervals depending on usage, parameter settings and environmental conditions. The predictive maintenance software provides recommendations for maintaining the nozzle. Finally, a dashboard supports operator activities like filament changes or nozzle cleanings.

The i-Maintenance toolset consists of a messaging bus and a set of adapters, for each of the external software components. The messaging bus serves as a communication layer and is responsible for receiving and distributing the information between those applications. The main role of the adapters is the translation of application-specific data formats into a common message format that is used by all participants of the messaging system. For the semantic description of data, the open OGC SensorThings [1] standard has been selected. This data representation requires just a minimal amount of mandatory information per message and is also linked to the complete datastream definition stored on a standardised SensorThings server. Each message contains a result value, two timestamps (phenomenonTime and resultTime) and the datastream identifier.

To meet the high demands of "smart factories" in terms of performance and stability, messages between the adapters are transported using the scalable, fault-tolerant data streaming platform Apache Kafka [2]. In contrast to other messaging protocols, such as MQTT or AMQP, Kafka is designed differently: To offload state processing from the brokers, more intelligence is put to the publishers and subscribers. This results in overall performance advantages, allows horizontal scaling and improves reliability. New applications and IoT protocols like OPC-UA, REST or MQTT can be connected with little effort via the adapters.

In order to set up a comprehensive digital twin for smart maintenance, all mes-

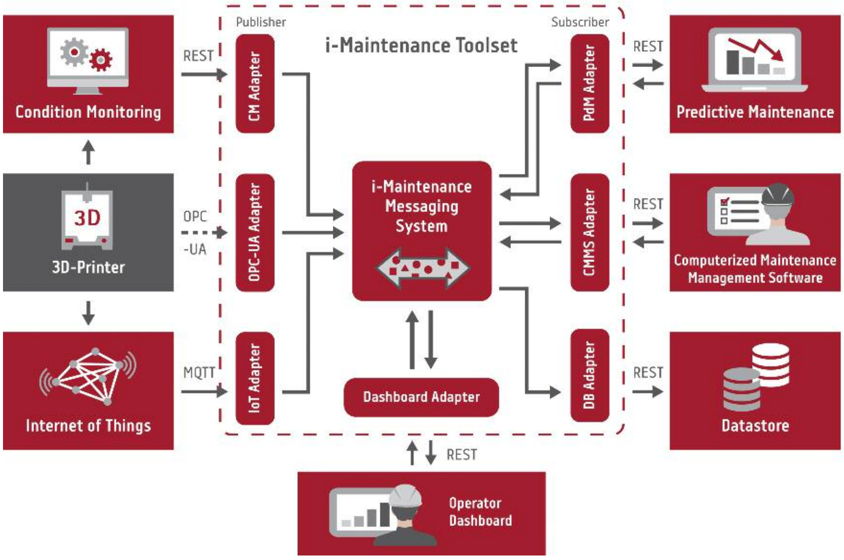

Figure 1: Architectural overview of the i-Maintenance toolset.

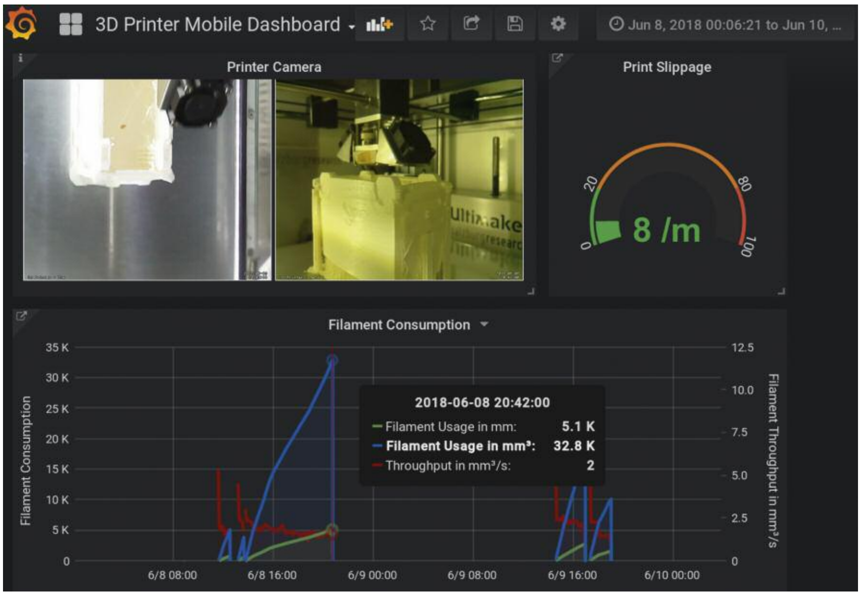

Figure 2: User-friendly analytics for real-time or retrospective investigation of failures.

Figure 3: Laboratory setting at Salzburg Research.

sages of all topics are streamed into a separate "datastore". Due to the common SensorThings format, the information can be effectively queried and filtered. As technology for implementing the datastore, we use Elastic Search from the "Elastic Stack" (https://elastic.co), which is also horizontal scalable and distributed: storage and processing power can be added by putting more nodes to the cluster. For a user-friendly visualisation of real-time sensor data and video streams, "Grafana" (https://grafana.com) is integrated, where the cause of production failures during the 3D-printing process can be investigated live or retrospectively (Figure 2). For advanced analytics of data generated throughout the production process, the "Jupyter" framework (https://jupyter.org) is connected. It enables collaborative work on the same project via browsers with a variety of interpreters like Python, R and Scala. This makes it possible to invite remote experts for data analytics and assessment, without the need to send huge amounts of sensor data and log-files. User-specific data analytics represents a frequently neglected aspect of a digital twin framework.

At the time of publication of this article, the i-Maintenance toolset is validated against a set of functional and non-functional criteria for digital twins in a maintenance scenario. In future, additional lifecycle and analytics features will be developed together with further adapters to cover more industrial protocols.

i-Maintenance is funded by the Austrian Federal Ministry for Digital and Economic Affairs (BMDW) and the Austrian Research Promotion Agency (FFG) in the COIN programme. Conducted by Salzburg Research, the development of the i-Maintenance toolset is supported by H&H Systems (ispro-NG), Messfeld GmbH (condition monitoring) and Intelligent Predictive Networks GmbH (inCARE).

Links:
https://srfg.at/i-maintenance
https://github.com/i-maintenance
http://www.maintenance-competence-center.at/

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Digital Twins as R&D Accelerators – The Case for an Open Source Ecosystem

by Cor van Kruijsdijk (Shell Global Solutions International bv)

Shell is using Digital Twin applications to improve operation, maintenance and safety, for example in chemical plants and offshore platforms.

In the early days of space exploration NASA introduced the concept of "pairing" to support operating, maintaining and repairing devices that are not in close proximity. The underlying ideas led to a white paper by Grieves [1] where he introduced the concept of a "digital twin". A broad definition can be found in Wikipedia: "Digital twin refers to a digital replica of physical assets (physical twin), processes and systems that can be used for various purposes". A more technical depiction of the fundamental landscape can be seen in Figure 1. In recent years digital twin applications have surfaced in many areas and landed the concept in Gartner's Top 10 Strategic Technology Trends for 2017.

In Shell, digital twins are deployed, for example, for (parts of) chemical plants and offshore platforms as well as smaller assets. They add value in improved operation, maintenance and safety. Moreover, in a drive to further digitalisation many more applications will come online in the near future. Most, if not all, of these will be targeting operating assets and will be data rich. Consequently, data-analytics has a prominent role to play. Digital twin applications earlier in the life cycle (conception, prototype) are scarce. Although many of the core-flow experiments in support of enhanced oil recovery are matched to computer models, these only use part of the digital twin paradigm.

The need for digital twins in R&D

The energy transition is an existential challenge for Shell as it impacts our two main pillars, fossil fuels and chemicals [L1]. In addition, it is taking place at an increasingly rapid pace. Significant technological breakthroughs are required to stay within the bounds of the Paris Agreement [L2]. As we are exploring the solutions of the future we need to learn fast and innovate at an even higher pace than traditionally done in our industry. Adopting a digital twin approach will get more value, faster out of our experiments. Our insights into the physical problem are enhanced by exploring the digital solution in places where no data exists. Moreover, it allows us to (digitally) pre-explore the solution space. We can preferentially target the most interesting parts in the solution space, thereby reducing the number of experiments. We can even explore parts of the solution space that are difficult (or even impossible), dangerous or very expensive to target with experiments.

However, during the conception or exploration phase of new technology we usually deal with a much larger solution space that furthermore has a much lower data density. Fortunately, the operational phase requirement of real time results can usually be relaxed in the conception phase. Inevitably we need to rely more on equation-based models than later in the life cycle. Often our problems, such as in electro-chemistry, are inherently multi-scale. Moreover, the transport processes that couple the small (e.g. catalysis) to the engineering scale have multiple drivers. Particularly at the meso-scale ("where chemistry meets physics") it is not unusual to encounter more than 10 relevant gradients. Usually the relative importance of the drivers (gradients) changes across several spatial (and temporal) scales. Meso-scale models typically require large domains (10^7-10^{10} voxels) and yield stiff equations. Although it is an active field of research, it is often limited to medium-sized domains, and incomplete physical descriptions. To achieve the goals set out above, we need to push the current boundaries.

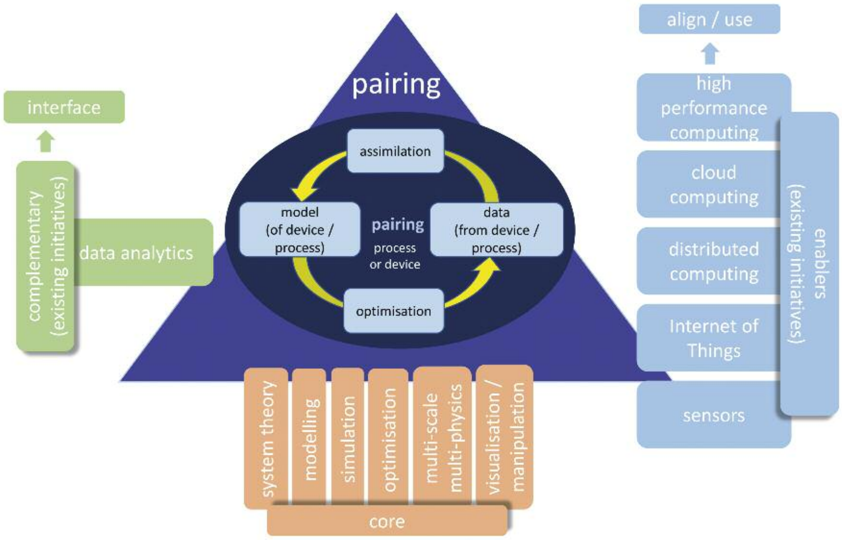
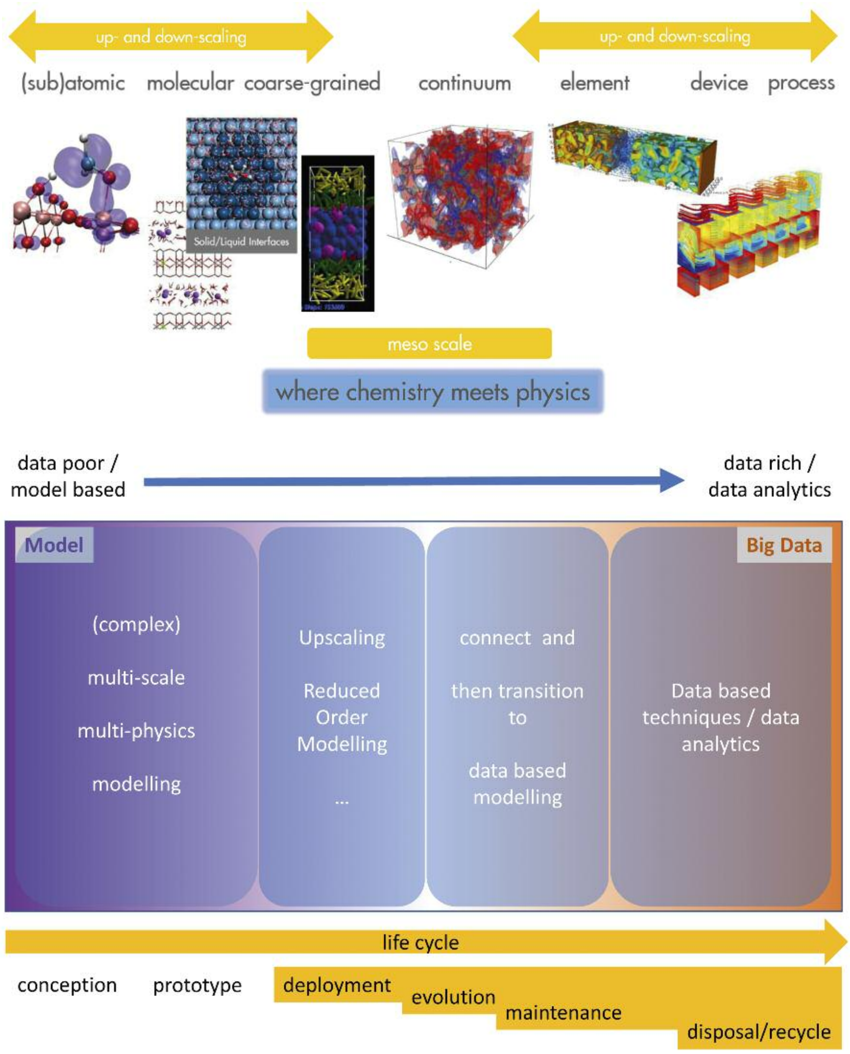


Figure 1: Digital Twin landscape.



An Open Source Ecosystem

Both the urgency of the problem domains as well as the complexity of the required multi-scale multi-physics models necessitates large scale collaboration. Effective solutions rely on algorithms that scale well on modern and future hardware. Moreover, an effective "digital twin" will be based on system-theoretical foundations, allow easy manipulation, insightful visualisation, extensive data-assimilation and large-scale optimisation; a truly multi-disciplinary challenge (see Figure 1). This collaboration relies on a versatile, fit-for-purpose, open source ecosystem. For all parties (academia, software vendors, start-ups, industry) to participate in this, it will need to allow for sustainable "business models" or drivers for all actors. Hence the ecosystem needs to provide for optimal access, transparency, modularity (largely open), but also proprietary modules, and even IP-protection (where required, for example, in the case of cross-industry participation). EU-MATHS-IN [L3] is working together with an extensive group of companies to get this topic squarely on the agenda of the next EU framework, Horizon Europe.

Links:
[L1] https://kwz.me/htI
[L2] https://kwz.me/htJ
[L3] https://kwz.me/htM

Reference:
[1] M. Grieves: "Digital Twin: Manufacturing Excellence through Virtual Factory Replication", white paper, 2014 http://innovate.fit.edu/plm/documents/doc_mgr/912/1411.0_Digital_Twin_White_Paper_Dr_Grieves.pdf

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Automatic Generation of Simulation-based Digital Twins of Industrial Process Plants

by Gerardo Santillán Martínez (Aalto University), Tommi Karhela (Aalto University), Reino Ruusu (Semantum Ltd), and Juha Kortelainen (VTT)

Simulation-based digital twins (SBDTs) of process plants can be used for a number of important industrial applications. They have various advantages compared to digital twins based on data-driven models. However, wider industrial adoption of SBDTs is hindered by laborious development of their underlying simulation model as well as by the lack of integration methods with the operational process. The Engineering Rulez research project has tackled these issues by developing a novel automatic model generation method as well as a simulation architecture based on OPC UA, a well-established industrial interoperability standard. The proposed SBDT automatic generation method aims to enable a wider industrial adoption of digital twins based on first principle models.

Ever-growing competitiveness in process industry pushes companies to increasingly rely on Industrial IoT solutions for improving operation performance and for increasing cost efficiency of process plants. Digital twins (DTs) of production plants are an example of IoT applications, which are becoming highly popular in process industry in sectors such as chemical, power generation, mineral processing, pulp & paper, and oil & gas. Since they are able to capture the structure and dynamics of the targeted plant, digital twins are a powerful tool that can be used for optimisation and for decision support of operational process plants.

Commercial DTs, commonly based on data-driven models, are developed purely from the available measured data of the targeted industrial plant. These systems rely on black-box models built to capture relations between the inputs and outputs of the plant. Consequently, they are fast to develop and they can be applied to obtain production forecasts or to detect certain production anomalies. However, since they are only based on measured plant information, their results cannot be used to analyse plant operation states that are not included in the collected data. Additionally, they require expert interpretation and are thus difficult to scale up. Moreover, applications based on data-driven DTs rely entirely on the automation and monitoring systems data to provide information about the current plant state.

Simulation-based DTs (SBDTs) are based on on-line simulation of first-principles models (FPMs). FPMs rely on engineering, physics or chemical knowledge to represent the behaviour of the plant. In SBDTs, a simulation model runs together with the plant while online and off-line estimation techniques synchronise the simulation state with the state of the targeted device or process. Information of the current state of the plant can be obtained from this simulation configuration. The underlying simulation model can be used to obtain high-fidelity predictions, including production forecasts of operating regions from which no measurement data are available. Furthermore, SBDTs can be used for developing operator training simulation systems, for production optimisation, or for troubleshooting and failure diagnoses.

SBDTs are a holistic tool for plant operation support of modern industrial plants. As such, developing the FPMs of SBDTs is a time-consuming and complex task. Although these issues can be partially solved by re-using existing models, developing FPMs remains laborious and expensive. Moreover, the lack of systematic approaches for SBDT generation, which address complex integration of the process with simulation systems and methods, limit wider industrial adoption of SBDTs.

The Engineering Rulez research project has aimed to develop an automatic generation method of SBDTs for industrial process plants, which addresses the pre-

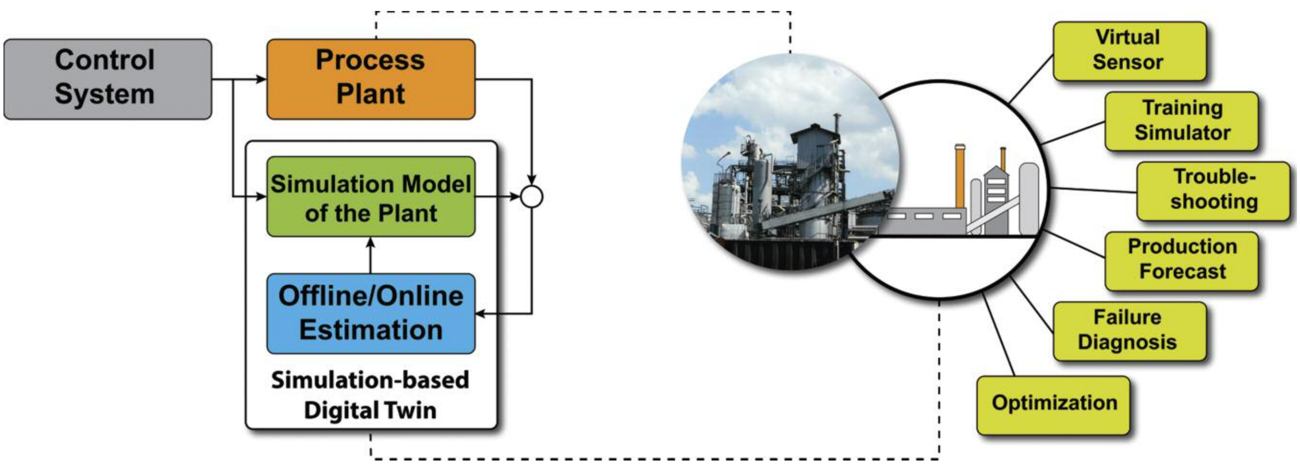

Figure 1. Simulation-based Digital Twin (SBDT) structure and its applications.

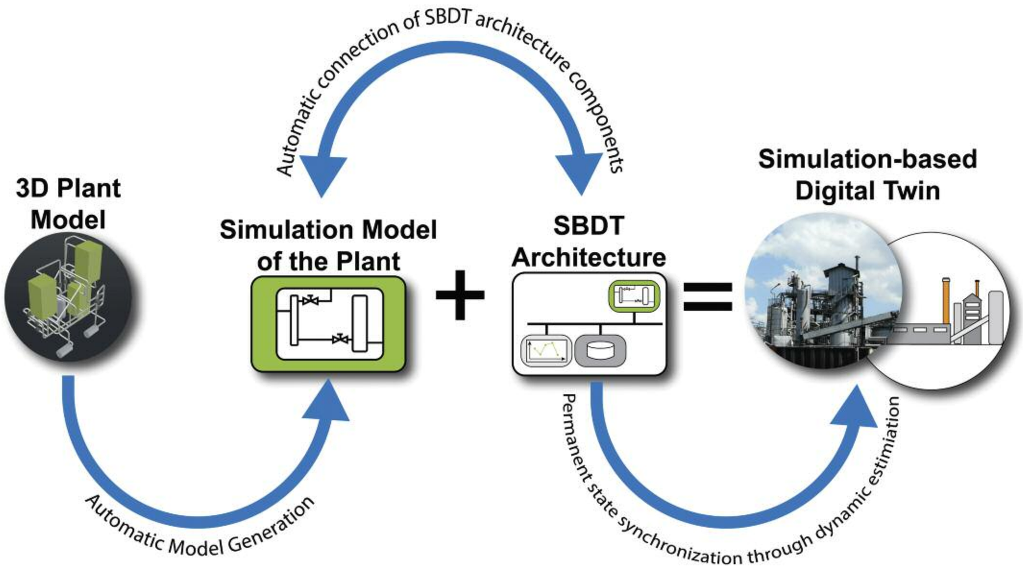

Figure 2. Automatic SBDT generation from 3D plant models.

sented shortcomings in order to increase industrial adoption of SBDTs. In the proposed approach, laborious FPM development is tackled by applying automatic model generation (AMG) methods.

Existing AMG methods utilise data from engineering sources, such as piping and instrumentation diagrams (P&ID), equipment technical data sheets and control application programs. However, it is not possible to generate high-fidelity dynamic thermal-hydraulic FPMs without information of the process pipeline network. In particular, key parameters for such FPMs are the head loss coefficients, which represent head losses due to elbows or branches in the pipelines. These parameters can be obtained only from information about the physical piping structure and are thus available only after a 3D pipe routing has been accomplished.

For this reason, our approach uses information available from 3D computer-aided design (CAD) models of the plant in combination with other engineering data for rapid development of high-fidelity thermal-hydraulic simulation models [1]. In the proposed AMG method, data included in the 3D plant model is used for calculating piping sections lengths, elevations as well as head loss coefficients of the pipeline network, and to automatically generate a thermal-hydraulic model. As a result, the fidelity of the simulation model is increased compared to the one obtained following existing methods.

After the first-principles simulation model is automatically generated, a newly developed lifecycle-wide online simulation architecture [2] is utilised to automate the generation of the SBDT. This architecture is used to automate the process of connecting the FPMs to the physical plant; to optimise the simulation model for its behaviour to closely mimic the real process; and to dynamically adjust the simulation results in order to permanently synchronise the simulated and real plant states. Furthermore, the developed architecture utilises the industrial interoperability standard, OPC UA, to avoid the need for point-to-point integration of various simulation instances and methods used over the course of the SBDT lifecycle. DTs are the cornerstone of the industrial digital transformation. The implementation framework proposed by the Engineering Rulez research project aims to enable a more efficient path for the implementation of SBDTs.

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How will Your Digital Twin be Born?

by Gábor Závodszky, Alfons G. Hoekstra (University of Amsterdam)

In-silico models of human physiology and pathology are aimed at progressing and complementing medicine in several ways. These models can reproduce physiological processes and events on multiple scale levels. The goal of the individual models is to help predict the outcome of a specific disease or to support the decision-making process during treatment.

Imagine having an in-silico representation for every physiologic process, for every organ of your unique body running on a computer. This idea forms the conceptual framework of the Digital Twin.

Digital Twins are an emerging technology representing the next step in patient specific health care. Your Digital Twin can provide a unique, personalised, fully operational blueprint of your body. This map represents your molecular, biochemical, physiological status.

Figure 1: A beating virtual heart.

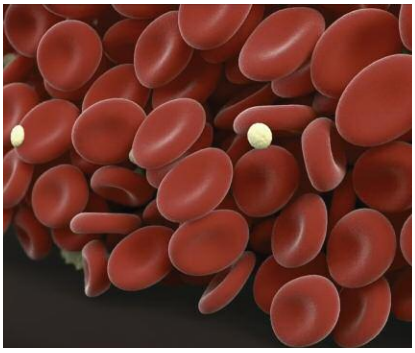

Figure 2: Simulation of flow of red blood cells and platelets.

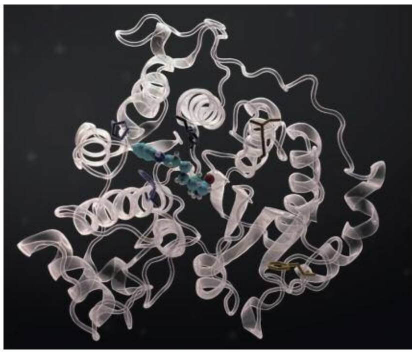

Figure 3: Simulation of drug binding on the level of proteins.

It can be used to pinpoint deviations from the healthy or "normal" state of your body and it is always there for you as a volunteer on which treatments of any disease you may have can be tested.

The Concept of being "Normal".

The meaning of "healthy" is historically defined against a wide biological envelope, against a large set of patterns observed on the population level. Your in-silico replica can refine this definition by specifying the patterns that are regular for a given individual, for you. This carries one of the biggest promises of this great endeavour, a significant contribution to personalised medicine: the possibility to design personal, fully tailor-made treatments for diseases, rather than basing the treatments on what is the best on average for a large group of patients.

In turn, however, applied on a population level, the Digital Twin can provide in-silico clinical trials, in which the computer models test the effects of a given medication. This should lead to faster and more cost-efficient introduction of new medication, as well as to a reduction in the use of laboratory animals in medical research.

The Birth of the Digital Twin

The conception of the "virtual self" was made possible by numerous technological achievements that expanded our understanding of electrical, chemical, and biomechanical pathways in our body. These developments are happening at an ever-increasing pace, ignited in the early 80s with the wide adoption of computer tomography, progressing through recent events, such as the first Food and Drug Administration accreditation in 2016. It provided a prime example on how a computer model can be useful in the cardiovascular treatment of patients.

Furthermore, detailed personal data is becoming available through multiple channels, for instance, due to the advance of molecular level non-destructive readout technologies but also due to wearable technologies providing continuously tracked physiological parameters.

The excess of information combined with the increase of accessible computational power yields the perfect ground for the Digital Twin to be born as a data-driven approach to personalised medicine.

One example of the many components (virtual organs) building up the "virtual self" is the digital counterpart of the human cardiovascular system, the Virtual Artery. This multiscale model computes the beating of the human heart as it pumps blood, a complex suspension of cells, through the vascular network. It simulates the cellular interactions inside the blood and between the blood flow and the vessel walls and it computes the reaction of the smooth muscle cells inside the wall. This system will yield information in unprecedented detail that can be used to identify diseases, evaluate effects of drugs, and design the most effective treatment.

Many similar components are currently coming together to synthesise the Digital Twin. A development which progresses as a mutual effort of a worldwide community aggregating large networks of researchers such as the community of the Virtual Physiological Human (VPH) or the CompBioMed H2020 project.

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Computational Design of Complex Materials Using Information Theory: From Physics- to Data-driven Multi-scale Molecular Models

by Vagelis Harmandaris (UOC & IACM-FORTH), Evangelia Kalligiannaki (IACM-FORTH) and Markos A. Katsoulakis (UMass Amherst, USA)

The development of novel materials with desirable properties, such as nanocomposites, polymers, colloids and biomolecular systems, relies heavily on the knowledge of their structure-property relationships. The prediction of such relationships is the subject of computational materials design. Molecular dynamics (MD) simulations at the atomistic level can provide quantitative information about structural and dynamical properties of molecular systems. The recent enormous advances in computational power allow us to perform intense atomistic-level simulations. However, the broad range of length and time scales appearing in such complex (e.g., macromolecular) materials still presents significant computational challenges, especially in tackling engineering and design tasks.

Model order, or dimensionality, reduction is a standard methodology used to broaden the family of materials studied via simulations. In such a scenario, a molecular system is described by the most relevant degrees of freedom via coarse-grained (CG) models, which are developed by averaging out details at the molecular level. Typical examples involve representing groups of atoms by a single CG particle, see Figure 1.

We follow a systematic methodology to acquire rigorous CG models from the analysis of microscopic data, obtained from atomistic simulations. The analysis procedure involves (i) the suggestion of a parametric, or non-parametric, CG physical model, as well as (ii) the multi-dimensional fitting over datasets taken from atomistic MD simulations, i.e., it is a model- and data-based approach. The source of our simulation data is a physical model (the atomistic model), whereas the desired CG model we look for is hybrid: it involves physics-based aspects, such as the proposed type of interaction between CG variables (force field), as well as data-driven characteristics, such as the estimation of the parameters that will be inferred; this makes the CG model a "digital twin", see Figure 2.

We focus on the study of materials both at equilibrium [1] and under non-equilibrium conditions [2]. For systems at equilibrium, and near equilibrium, there is a direct connection between structural properties and CG interaction potentials (the force field in the CG level), via the potential of mean force (PMF) concept, which can be used to approximate the exact corresponding CG model. The development of rigorous CG models for materials far from equilibrium is a much more complex problem. At the same time, such systems are of great interest for most engineering applications related to nanotechnology, polymer processing, biotechnology, etc.

The challenge in the inference problems for systems out of equilibrium is that the time series data sets representing the coarse variable trajectories are both strongly correlated and relatively few, due to their high computational cost, setting up another "twin challenge". In contrast, current machine learning methods typically address big and independent datasets. Indeed, many problems in machine learning involve classification, analysis, and predictions, using data sets of points which are independent of each other; for instance, to correctly predict the digit between 0-9, given images of handwritten characters. However, this is not the case in many applications involving physicochemical systems, where dependencies and correlations in space/time and between model elements (molecules, parameters, and mechanisms), as well as couplings between scales and physics (from quantum, to atomistic to meso/macro-scale) are the norm, rather than the exception. Moreover, although the exact CG dynamics is known and described by a stochastic integro-differential system with strong memory terms, it is computationally intractable, and approximations of the CG dynamics are essential.

Recently we have developed an optimisation approach to retrieve a best-fit approximate CG evolution model, i.e., the path-space variational inference for CG [1]. Variational inference is a central tool in machine learning where the inference problem is tackled approximately using an optimisation principle. For CG dynamics and nonequilibrium models, our optimisation principle

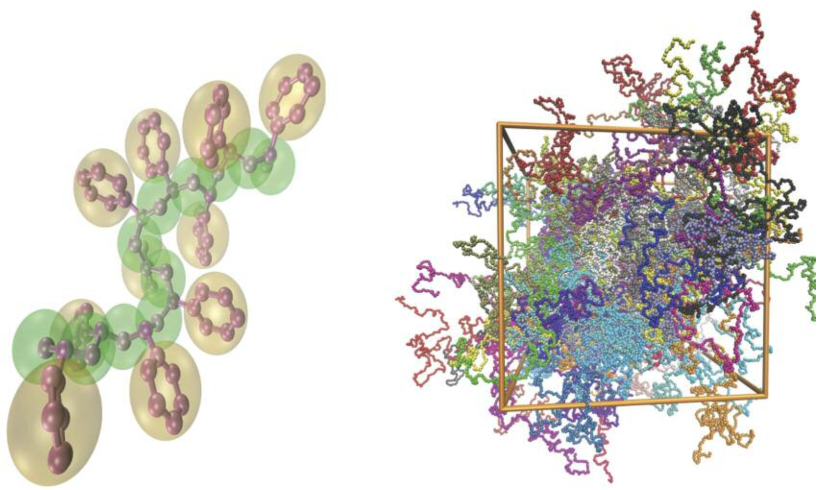

Figure 1: Caption: Model reduction (coarse graining) in macromolecules: A single polymer chain in atomistic and CG representation (left), and a snapshot of a CG bulk polymeric system (right).

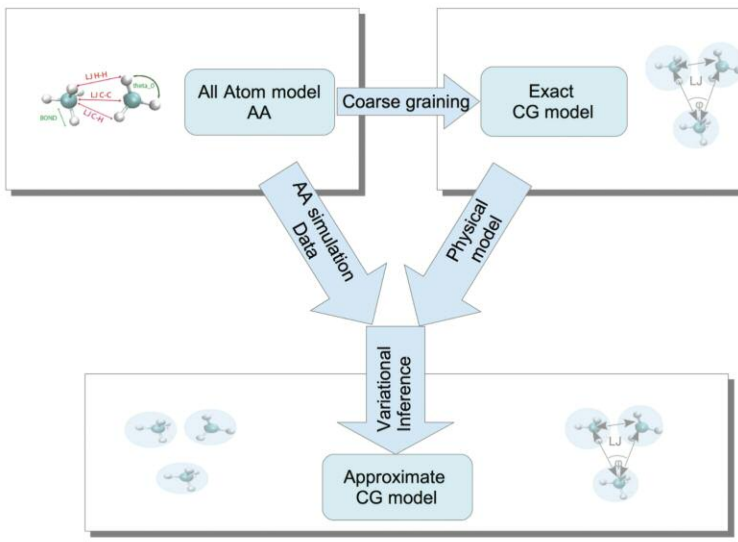

Figure 2: Caption: A schematic description of the model reduction in molecular systems and the effective CG models through variational inference.

involves the minimisation of information loss between time series, introduced by coarse-graining, between the probability distribution of the trajectories (time series data) of the coarse variables defined by the atomistic and the coarse dynamics.

This research was applied successfully to benchmarking problems, such as simple liquids, alkanes at transient and equilibrium regimes [1,2], as well as to complex reaction networks [3]. Current and future work concerns computational applications of the path-space variational inference approach to complex macromolecular systems and multi-component nanostructured materials at equilibrium as well as beyond equilibrium.

Our research team is an interdisciplinary team composed of chemical engineers and applied mathematicians. We have long-standing experience in model reduction methods, mathematical and computational modeling of complex systems, and variational inference methods, [L1, L2].

Three different institutes are involved in the research project: University of Crete (Greece), Institute of Applied and Computational Mathematics – FORTH (Greece), and UMass Amherst (USA). We also have several years' active collaboration with research institutes worldwide.

Links:
[L1] http://macomms.tem.uoc.gr/
[L2] https://kwz.me/htQ

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Afivo – A Framework for Efficient Parallel Computations with Adaptive Mesh Refinement

by Jannis Teunissen (CWI and KU Leuven) and Ute Ebert (CWI and TU/e)

We have developed a framework for efficient 2D and 3D computations on adaptively refined grids, which can be used on shared-memory computers. By using efficient methods, we aim to make interactive (quick!) simulations possible on modest hardware.

Some physical systems evolve on widely different spatial and temporal scales. Computer simulations of such systems can often be sped up by many orders of magnitude if the resolution of the simulations is cleverly varied in space and in time, which is referred to as adaptive mesh refinement (AMR). The use of AMR is particularly important for 3D simulations. If, for example, the resolution in a region is reduced by a factor of four, the number of unknowns is reduced by a factor of 64 (four cubed)!

For computationally expensive simulations, a balance has to be struck between adaptivity and performance. CPUs and GPUs work most efficiently when they are given structured data, for which nearby values in space are also nearby in the computer's memory. This is the reason that "structured" adaptive mesh refinement is popular. With structured AMR, an adaptive mesh is constructed from smaller grid blocks that are individually suitable for efficient computing. A list of frameworks for structured AMR is given in [L1]. Of course, such frameworks also employ parallelization, and many of them are aimed at large-scale simulations on super-computers.

Since 2015, the Multiscale Dynamics group at CWI has been busy developing

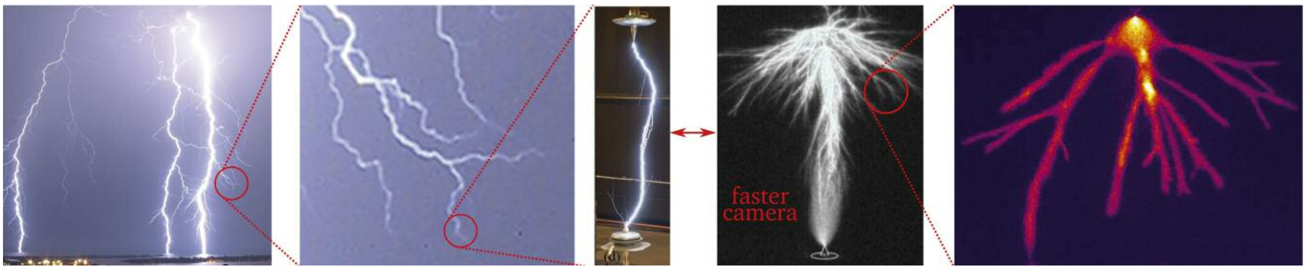

Figure 1: If we could keep zooming in on lightning strikes, we would eventually see streamer discharges (the centimetre-long channels on the right). [Image credits from left to right: John R. Southern, P. Kochkin, T. Briels].

yet another framework for structured AMR simulations, called Afivo [1][L2]. One of the distinctive features of Afivo is that it employs shared-memory parallelism (using OpenMP), and no distributed-memory parallelism (using MPI), which is common in other frameworks. This makes it simpler to implement and test new AMR algorithms, because there is no need for load balancing or explicit communication between processes. On desktops or single compute nodes, shared-memory parallelism also tends to improve performance. The drawback is of course that the framework cannot be used on distributed-memory systems.

Other key features include the bundled geometric multigrid methods, which can be used to rapidly solve elliptic partial differential equations such as Poisson's equation. These methods are ideally suited to structured AMR computations, and on current hardware we can achieve solution times below 10 nanoseconds per unknown. This means that simulations with up to hundreds of millions of unknowns can be performed on desktops or single compute nodes.

For the visualisation of the corresponding AMR data, output in an efficient data format is supported.

Application: Simulating Electric Discharges

In our group, we study electric discharges, which are prominent examples of multiscale phenomena. An example is shown in Figure 1. A lightning strike can be kilometres long, but its growth is made possible by much smaller plasma channels that are perhaps only a few decimetres long and millimetres wide. These smaller channels are called streamer discharges, and they in turn contain structures that are only a few micrometres in size. Being able to simulate streamer discharges is not just important to understand lightning, but also because they occur (and are used) in many high-voltage applications.

Based on the Afivo framework, we have developed a code to efficiently simulate streamer discharges. An example of a 3D simulation is shown in Figure 2. The ratio between the domain size and the finest mesh spacing is typically about four orders of magnitude; the ratio between simulation time and the time step is similar. A big advantage of having an efficient AMR simulation code is that smaller (2D) simulations can be performed in minutes instead of hours or days [3]. This allows for a much more interactive investigation of the simulated system, which we think is crucial in making computer simulations a viable alternative and complement to lab experiments.

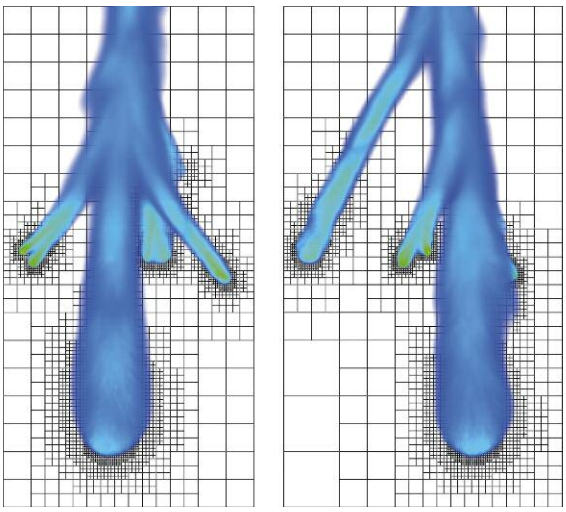

Figure 2: Two views at an angle of 90° on the electron density in a 3D streamer discharge simulation [2] [L3], with the numerical grid projected underneath. Each visible grid cell actually corresponds to a mesh block of 8x8x8 cells. The computational grid contains tens of millions of cells, and changes frequently to track the developing discharge channels.

Outlook

Thus far, we have focused our efforts on efficient computations in simple geometries (e.g., rectangular computational domains). In the coming years, we aim to add support for the embedding of curved objects like electrodes, insulators or droplets, while keeping the computational efficiency high.

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Links:

[L1] https://kwz.me/htW
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Securing Cyber-Physical Systems through Digital Twins

by Matthias Eckhart (TU Wien) and Andreas Ekelhart (SBA Research)

In recent years, the concept of digital twins has received increasing attention. Virtual replicas of cyber-physical systems (CPSs) can be leveraged for monitoring, visualising and predicting states of CPSs, leading to new possibilities to enhance industrial operations. Yet, the benefit of this concept goes beyond typical Industry 4.0 use cases, such as predictive maintenance. Recent efforts explore how digital twins can increase the security of CPSs.

The adoption of new technologies that follow the Industry 4.0 vision of an interconnected factory significantly increases the attack surface, and thus introduces new attack vectors. Considering that the security of CPSs has a direct impact on safety, implementing adequate security measures is vital. As a result, a holistic security solution that not only protects the CPS during operation, but rather throughout its entire lifecycle is highly desirable. More specifically, such a security solution should aim to (i) support the identification of security weaknesses in the specification, (ii) allow the execution of security and system tests without disrupting physical processes, (iii) monitor the physical process under control, and (iv) detect intrusions and other abnormal conditions of the CPS.

To implement the aforementioned use cases, researchers at TU Wien and SBA Research have been experimenting with the concept of digital twins. While the term “digital twin” typically refers to a data-driven or physical model of a system, we use it to describe an emulated or simulated device that may be connected to an emulated network. In the context of this research, digital twins reflect the correct behaviour of their physical counterparts, as specified by experts from the industrial automation domain. Thus, deviations between the physical device and its digital twin may indicate either malicious behaviour or faults. Furthermore, since the digital twins run in an isolated, virtual environment, they can be analysed in depth without risking the disruption of live systems.

The CPS Twinning framework [1] is an experimental prototype to implement these concepts. As illustrated in Figure 1, the digital twins are generated completely from the specification of the CPS, which consists of artefacts that express engineer and domain knowledge. Ideally, the specification has already been created during the engineering process. Furthermore, security and safety rules (e.g., thresholds for process variables) can be defined in the CPS's specification, providing the means for detecting abnormal conditions in digital twins.

In essence, the proposed digital-twin framework comprises a generator component and a virtual environment. The generator parses the specification in order to create the digital twins in the virtual environment. The virtual environment on the other hand, provides an emulated network stack that the emulated or simulated virtual devices can use for communicating with each other. Moreover, the framework supports two modes of operation, viz. simulation and

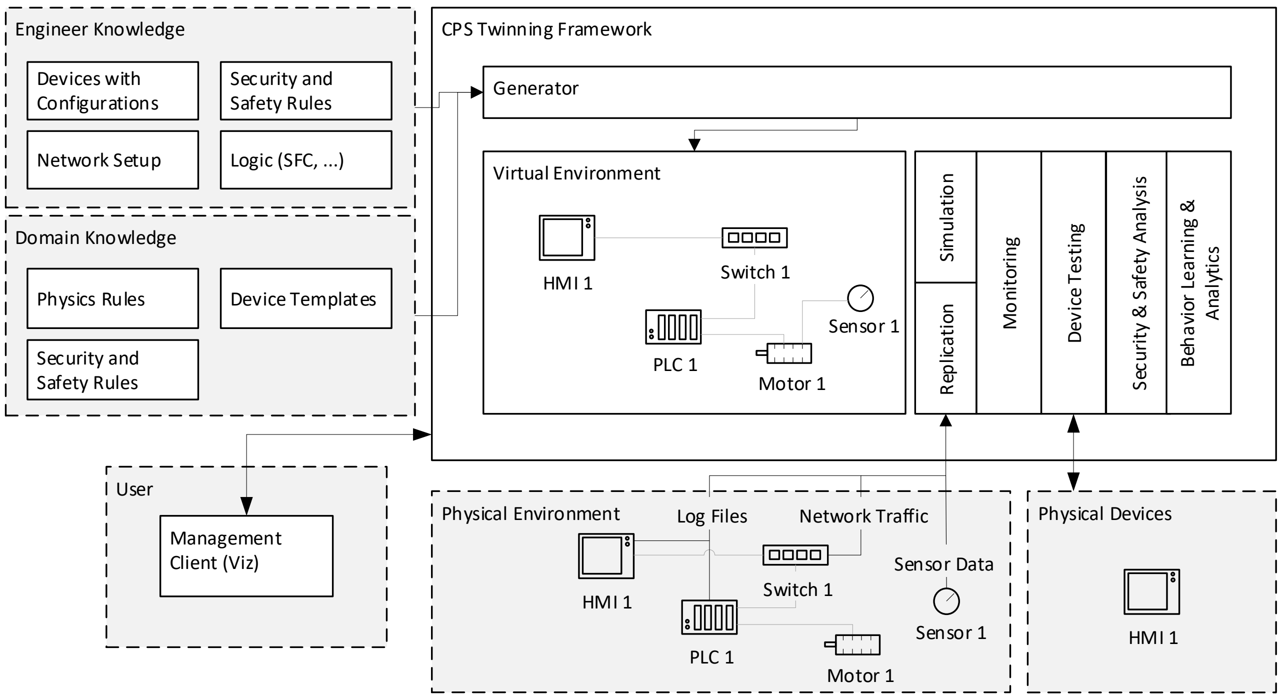

Figure 1: Architecture of CPS Twinning [1], which consists of the generator component, the digital-twin execution environment and modules that implement the use cases.

replication. In simulation mode, the digital twins run independently from their physical counterparts, e.g., to conduct security tests. In contrast, the replication mode mirrors the physical devices' program states to their digital twins. In this mode, malicious behaviour can be detected in two ways: First, a comparison between the inputs and outputs of physical devices and those of digital twins may reveal differences that would indicate malicious behaviour or faults that caused the real devices to deviate from their virtual replicas. Second, if abnormal conditions of the physical process emerge in the virtual environment as well, the framework is able to detect violations of safety and security rules, by continuously monitoring the state of digital twins.

In [1], we present a proof of concept to demonstrate the feasibility of the proposed approach. We used AutomationML [2] as a data format, to specify our exemplary production system. In addition to the CPS's specification, we explicitly defined safety and a security rules. The prototypical implementation of the framework is based on Mininet [3] and integrates a transcompiler for IEC 61131-3 programming languages as well as a Modbus TCP/IP stack. In this way, we were able to equip the digital twins with the required features to replicate the component logic of the physical devices that are part of our test bed.

For future work, we intend to focus on the simulation aspects of digital twins by developing a feature that would allow users to recover historical states of digital twins and replay their execution. In this way, certain scenarios can be repeated for further analysis, e.g., to understand the propagation of malware.

Link:
Source code of CPS Twinning on GitHub: https://kwz.me/hds

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Enabling Security and Safety Evaluation in Industry 4.0 Use Cases with Digital Twins

by Markus Tauber (FH Burgenland) and Christoph Schmittner (AIT)

The digital twin of a system should contain not only the existing information but also an up-to-date picture of the current status. While this is easy with physical properties, which can be measured by sensors, it is more challenging to measure and to provide an up-to-date picture of properties like security and safety. We have investigated the modelling of such dependencies in use cases related to transparency as well as to self-adaptability. Based on our experience we propose further extensions of domains like reliability. This also has the potential to provide legal support to Industry 4.0 use cases when required.

The uptake of technologies and approaches from the Internet of Things (IoT) together with flexible Cloud-based support technologies has enabled numerous and diverse digitisation and Industry 4.0 scenarios and use cases, ranging from smart manufacturing to smart-buildings and smart farming. Each domain has a different environment, and an application must be able to react, i.e. to be smart, to changes in the environment. Such changes need to be monitored and it is important that the application still operates in a trustworthy manner in the face of environmental changes.

Digital twins can help to organise and handle all the data that is generated by IoT elements. Digital twins are a digital representation of a real system, with the history of all changes and developments. Figure 1 gives an overview of how Industry 4.0 is structured and divided between the "real" and the "digital world". The starting point was to have a collection and a standardised digital representation of the real or physical "thing" for easier management. The digital twin is intended as a shell that contains and manages, depending on the application and needs, different sub-models [3].

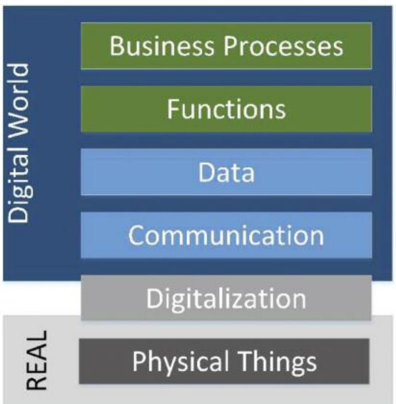

Figure 1: Industry 4.0 Layer-Model.

Although there are already security and safety oriented sub-models based on the IEC 62443 and IEC 61508/61511 these are currently intended as static information. From [1]: "Administration Shell (=digital twin) of Smart Manufacturing Components should be able to carry the (security-) information”. This is in our opinion insufficient for dynamic and changeable IoT devices where the system, which is providing a service, could be not only distributed geographically but also be managed by multiple parties and be used in changing environments and domain contexts. To ensure secure, safe and reliable operation it is necessary to have a constant view of the configuration and influenced security and safety properties. This is also important for legal reasons – which could be considered an additional dimension of the digital twin, which often considers the modelling of aspects in the physical dimension in the cyber dimension.

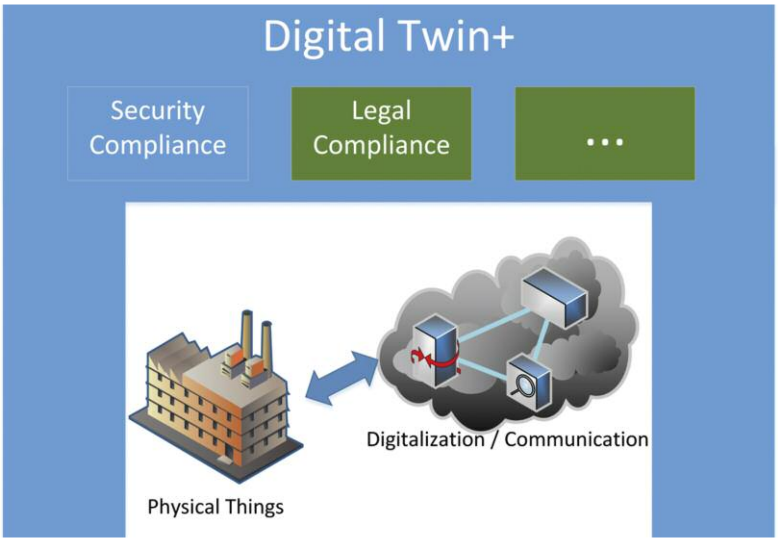

Figure 2: Digital twin with compliance.

Figure 2 gives an overview of the intended architecture. Besides the “physical thing” network, security and safety are considered as parts of the thing, monitored and stored in the digital twin. If an organisation can demonstrate that, a system is complying to certain security and safety standards by assuring that the required properties are fulfilled, legal and contractual obligations are easier to meet. Regardless of the domain, something that individual applications tend to have in common is that sensors and actuators interact with some cloud-based monitoring and control mechanism. Such cloud-based IoT solutions in this context can be a public cloud service such as “Microsoft IoT Hub” [L1], or a private cloud environment such as “VMware IoT Solutions” [L2] or even a physically very close entity, such as the hardware “Arrowhead local cloud” [2] infrastructure.

Methods and tools for analysing and monitoring the effect of a change and giving a holistic and easy to understand picture are not yet available. For instance, SySML is able to capture parts of the behaviour in state machine diagrams where the different states and potential transitions of individual components can be modelled but this is not focused on dependencies between security, safety and related dependencies based on larger composition of components cannot be described.

This particularly important in terms of effects on and interactions between security, safety and reliably. We focus on security and safety because of the potential exploitation of IoT devices as bot nets or industrial attacks, for instance. Safety is important since many of the IoT use cases interact with and affect the physical world, with risk of human or environmental harm. Security is also paramount because automatic actions must be able to rely on the data that is provided [3].

In the past we have worked on identifying related issues during design time in cases where trustworthy components are required and depicted this in a meta model [4]. We have also used this approach to model and describe dependencies and components in systems which adapts itself to a changing environment [5].

Based on our recent experience we propose to consider multiple dimensions when talking about a digital twin. We have done this with safety and security, and realised that there are more dimensions to consider. Each of them has to be described in a way specific to its domain and then linked to the other dimensions, i.e. the physical world, the digital application, cyber security, safety and in a next step reliability. This will allow us to verify the degree to which an automatically or autonomously triggered action can be based on trustworthy or reliable data. Recording this information will also support legal cases. An integration of such a topic to digital twins would provide a powerful method and tool for designing future complex and smart systems of systems.

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A Digital Twin Architecture for Security, Privacy and Safety

by Violeta Damjanovic-Behrendt (Salzburg Research)

We have designed a digital twin prototype for detecting security, privacy and safety critical issues for the smart automotive sector, based on work done in the ongoing IoT4CPS project (Trustworthy IoT for cyber-physical Systems.

The ability of smart cyber-physical systems (CPSs) to interconnect and merge into the ubiquitous Web of Things (WoT) infrastructure, facilitates the reuse of web technologies for future application development and reduces implementation time and effort. In practice, however, digital twin platforms are often built as closed, commercial systems, again limiting the pervasiveness of the technology. Thus, in IoT4CPS we design an open source digital twin prototype that employs machine learning (ML) for behavioural analysis and forecasting of security, privacy and safety measures. The proposed prototype creates an open source environment that comprises the following three technology blocks: (i) data collection and management, (ii) computational model management and (iii) (micro-)service management.

Data Collection and Management

One of the desired features for the digital twin is the ability to accurately simulate, analyse and predict real-world events and situations. In order to do so, digital twins require a collection of data describing the physical world, context, events and situations to be "mirrored" in the virtual space. The collected data include expert knowledge, historical data, inferred data, as well as data integrated from other enterprise systems and third-party systems.

Computational and Representational Model Management

Digital twins require a collection of models, e.g. data computational models (dynamic, behaviour models including statistical packages for ML, analytics, optimisation) and representational models (static, structural models including semantic data models, NoSQL, relational data models, rule engines). Data computational models perform analytics and processing along the entire product lifecycle phases, supporting system models, functional models, manufacturing computation models [1]. By employing ML algorithms (e.g. deep learning for neural networks to learn anomalies of the system), inferred data learned during the run time can be incorporated into the digital twin knowledge base, enabling continuous learning and improvement of features of the digital twin.

Service Management

To effectively monitor and simulate the physical world and perform computations leading towards intelligent decision-making for data and process lifecycle, digital twins require a collection of services, e.g. services for real-time state monitoring of the physical product and processes; services for real-time data management and asset management; services for real-time product failure analysis and prediction (anomaly detection); services for application security (authentication, authorisation, etc.), and more.

A Digital Twin Microservices Architecture

Our architecture of the digital twin follows the microservices approach, and consists of the Data Management, Model Management, Service Management, Virtualisation and

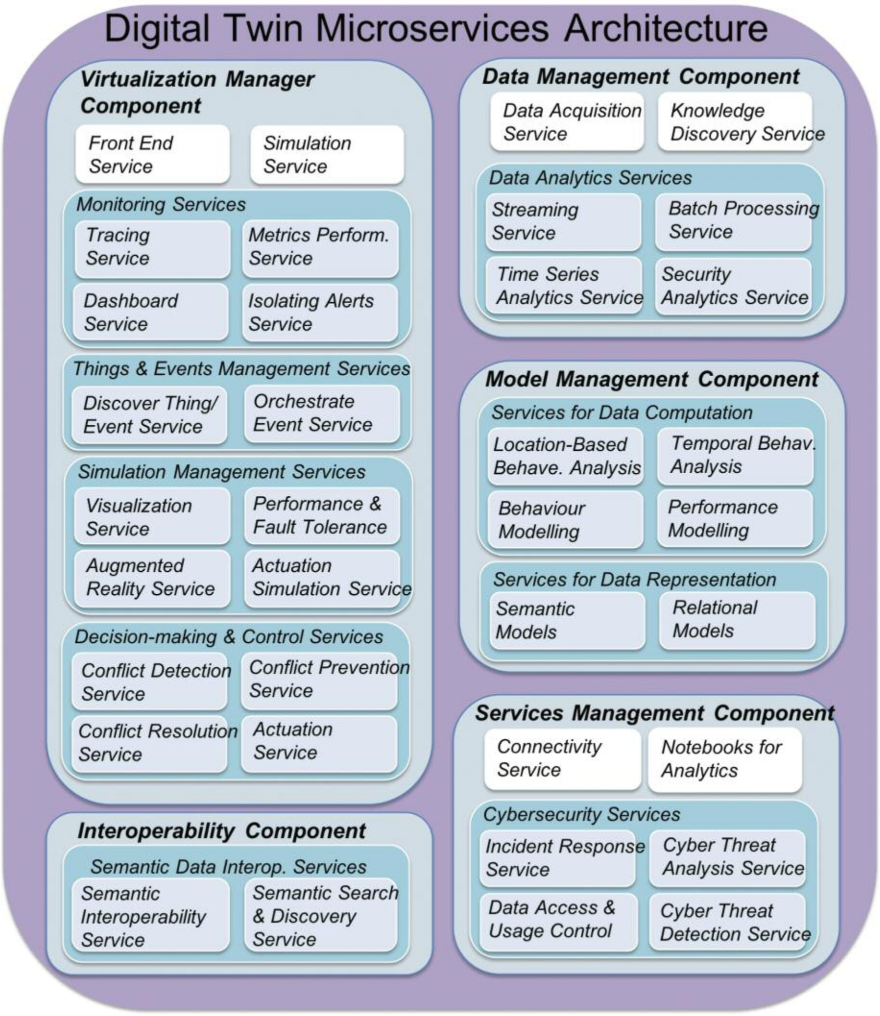

Figure 1. Microservices Architecture of the IoT4CPS Digital Twin Prototype.

Interoperability components, as shown in Figure 1.

The Data Management Component includes Data Acquisition Service, Knowledge Discovery Service and Data Analytics Services for streaming, batch- and time series-oriented processing, and security-oriented analyses. The Models Management Component includes (i) Services for Data Computation supporting either temporal or location-based behaviour analysis or performance modelling, and (ii) Services for Data Representation that could be semantic or relational models. The Services Management Component offers services through notebooks for customised analytics, and performs various cybersecurity tasks, e.g. data access and usage controls, threat detection and analysis service, incident sharing and incident response service. The Virtualisation Manager Component operates through front-end services, monitoring services, things & events management services, simulation and simulation management services, and decision-making and control services. Monitoring Services offer end-to-end transaction tracing (Tracing Service), measuring performances and operations of the system (Metrics Performances Service), the ability to isolate problems, alerts, and anomalies (Isolating Alerts Service) and dashboard visualisation services for monitoring interactions and cross-service visibility (Dashboards Service). These services help developers to understand the overall user experience while breaking information down into smaller applications. For example, Simulation Management Services perform visualisation (Visualisation Service) which could use a form of Augmented Reality (Augmented Reality Service) for simulating a specific actuation (Actuation Simulation Service) and measuring system performances and fault tolerance (Performance & Fault Tolerance Service). Finally, the Interoperability Component is designed to offer interoperability mechanisms at the data level (Semantic Interoperability Service and Semantic Search and Discovery Service).

Conclusion

The Smart Automotive sector is fragmented by different strategic alliances of manufacturers. This makes it difficult for research to offer novel, alternative approaches to autonomous decision making, context- and situation-aware controls and self-adaptation, all of which are required to realise smart CPSs. Hence, in IoT4CPS, we design a flexible digital twin open source solution that can offer alternatives to proprietary technology stacks developed in corporate automotive research.

This research has been funded by the Austrian Research Promotion Agency (FFG) and the Austrian Federal Ministry for Transport, Innovation and Technology (BMVIT) within the "ICT of the Future" project IoT4CPS [L1].

Link:
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Digital Shadows in the Internet of Production

by Matthias Jarke (Fraunhofer, FIT and RWTH Aachen), Günther Schuh, Christian Brecher, Matthias Brockmann and Jan-Philipp Prote, (RWTH Aachen and Fraunhofer IPT)

Due to highly sophisticated, specialised models and data in production, digital twins, as defined as full digital representations, are neither computationally feasible nor useful. The complementary concept of digital shadows will provide cross-domain data access in real time by combining reduced engineering models and production data analytics.

Manufacturing is currently at a tipping point induced by digital globalisation. A broad range of converging technologies and concepts based on connectivity and data – from machine learning, to cloud computing, to the Internet of Things – will lead to a massive shift of the manufacturing sector. The vision of our research cluster "Internet of Production" describes the RWTH Aachen University with Fraunhofer's research roadmap concerning this development. Within an interdisciplinary team originating from the DFG-funded Cluster of Excellence "Integrative Production Technology for High Wage Countries" [1], researchers from engineering, computer science, business and social science are shaping the future of production technology. In addition to the RWTH Laboratory for Machine Tools and Production Engineering WZL and the Fraunhofer Institute for Applied Information Technology FIT, more than 30 institutions are involved in this initiative.

The scientific core concept of the Internet of Production is called "digital shadow". Extending [2], we distinguish digital shadows from the popular concept of digital twin. The "digital twin" is an active simulation aiming to run in parallel, and interact with, a "real" physical, technical, socio-technical, or business system. In engineering, digital twins are often executions of very rich and powerful, multi-parameter models – in the continuous case complex differential equation systems, in the discrete case, they might represent an entity like a business process model instantiation, for example. The interacting pair of real system and digital twin forms a cyber-physical production system (CPPS).

Digital shadows are abstracted traces captured by sensors of the "real"

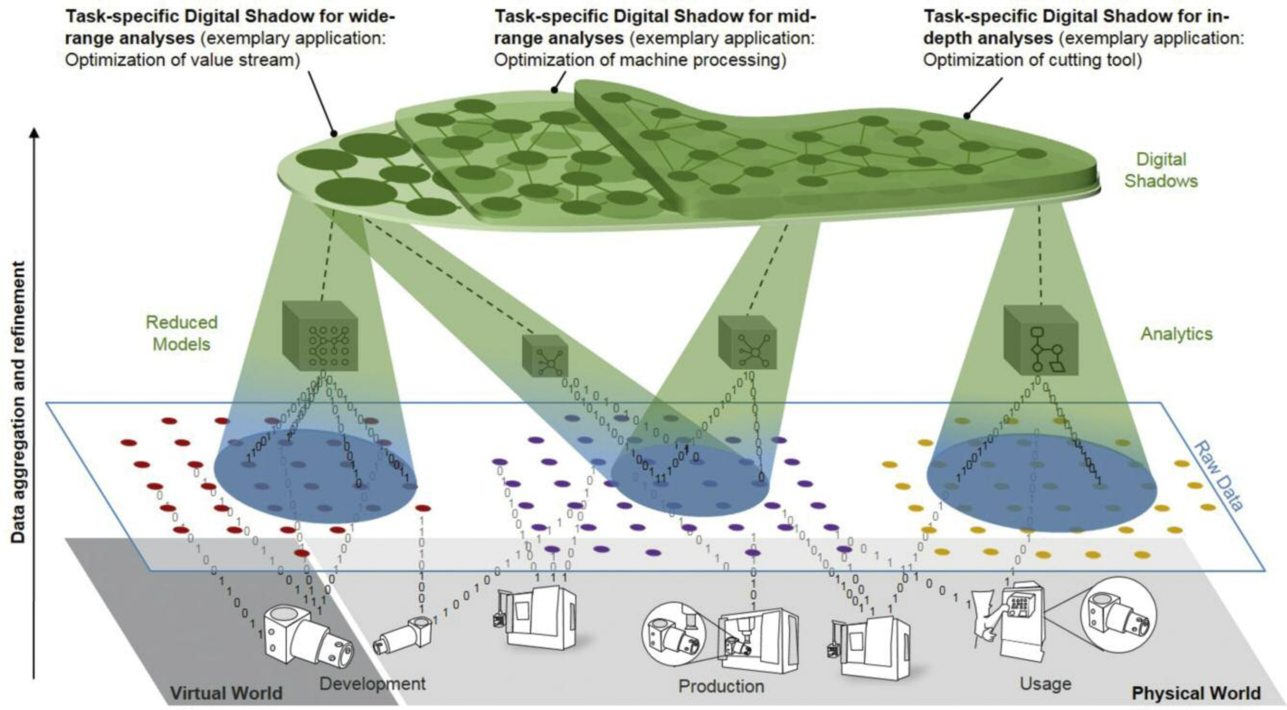

Figure 1: Digital Shadows embedding reduced model in deep learning enable adaptive scheduling in steel production (source: IBF/WZL, RWTH Aachen University).

system, its digital twin, or the interactions between both. The abstractions can be refined physical or empirical models which represent certain aspects of the structure, behaviour, and rationale (goals, obstacles) of CPPS for particular purposes. Digital shadows also provide semantically adequate and context-aware data from production, development and usage in real time with the adequate level of granularity – analogous to proposed travel routes in navigation systems such as TomTom or Google Maps that combine abstracted massive live cell phone data with formal map graphs.

Experience from the Production Cluster spawned our hypothesis that a well-designed collection of digital shadows is more promising for comprehensive production engineering, operation, and management than a full-scale digital twin. Firstly, experience over the past 50 years shows that the growth of production-related data will always outpace our ability to store, communicate, and analyse them. Secondly, digital shadows explicitly address the fact that data and models in producing companies are not just heterogeneous but also usually available only within proprietary systems. This restrains accessibility across engineering domains and organisations. Even with adjacent domains, instant access to data is hardly possible, often leaving engineers with outdated or false information.

An excerpt from an interdisciplinary case study [3] may demonstrate how a digital shadow of production can enable diagnosis, prediction and cross-domain recommendations in domain-specific real-time. Within the lifecycle of steel-based products such as the B pillar in a car (Figure 1), the energy-intensive hot-rolling stage produces sheets with a given height and microstructure through a carefully planned schedule of rolling and cooling steps. Traditionally, finite element simulation (FES) evaluates a manually designed schedule in terms of parameters such as time, energy consumption, and expected result quality. Within the Production Cluster [1], an interdisciplinary team [3] has shown that the FES

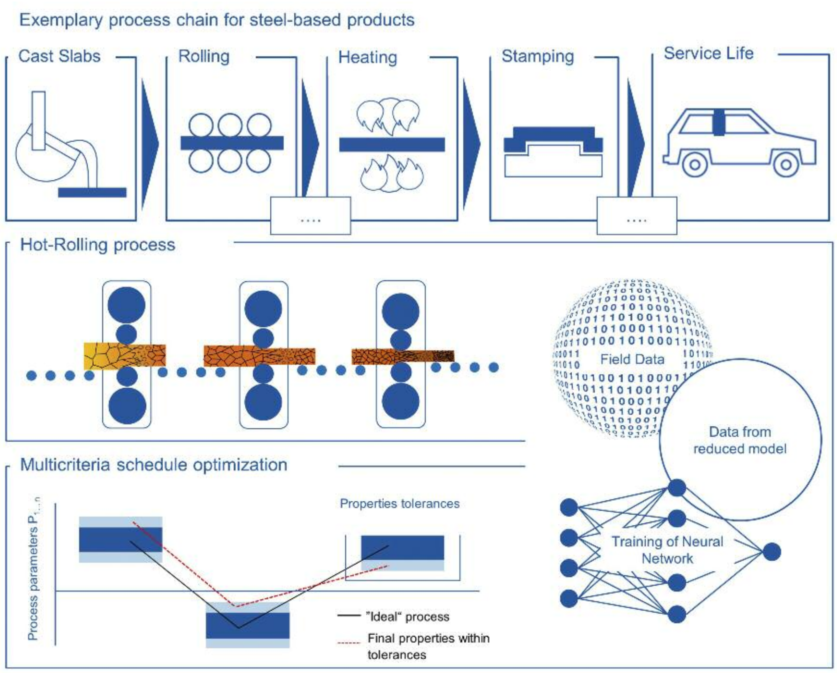

Figure 2: Linked Digital Shadows improve multi-level overall operational efficiency (OEE) in production (source: WZL, RWTH Aachen University).

can be adequately approximated by six reduced analytical models concerning heat transfer (temperature distribution), mechanical load (stress, strain), and microstructure evolution (grain size, recrystallization), reducing the evaluation time from 30-240 minutes by six orders of magnitude to less than 50 milliseconds.

However, this model-based digital shadow still only concerns a single proposed schedule. It can neither support multi-criteria schedule optimisation nor the ability to dynamically adapt a running schedule when context conditions change, forcing practitioners to avoid required expensive and extremely energy-intensive rework by over-engineering. With the digital shadow approach, the reduced models are embedded in a deep learning neural network that learns near-optimal schedules for desired outputs and given context parameters data-mined from live sensor data. This enables not just real-time adaption and thus more "tolerant" plans, but also creates digital shadows for better synchronisation with later steps in the overall production network. Given that 90% of all steel-based products worldwide undergo hot-rolling, enormous impact on energy consumption and ecological footprint can be expected from just this rather "small" innovation.

Such early experiments in digital shadows for real-time data-driven machine control, process mining, and agile production management make us confident that well-designed digital shadows may significantly increase overall equipment effectiveness (OEE) by offering an abstraction for controlled knowledge sharing (cf. Figure 2): Manufacturers currently only leverage a fraction of the capabilities of their production machinery while vendors of production machinery have detailed knowledge about their machinery, but lack access to the domain experience of their customers. Combining both sides of domain knowledge will lead to increased performance far exceeding that of next-generation hardware.

Link:
http:// www.production.rwth-aachen.de

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SERVUS: Agile Engineering of Digital Twins deployed in IIoT Platforms

by Thomas Usländer (Fraunhofer IOSB)

Representing real world objects as digital models has been a central topic of computer science for many years. However, in order to reduce the complexity and owing to the memory and processing limitations of IT devices, the digital models have always been quite tightly focused. Digital Twins (DT) are about to change this. The DT concept conveys the idea that digital representations should possess many of the essential properties of their real-world counterparts along their whole lifetime and even before and beyond. We propose an engineering methodology that allows an engineer to systematically motivate and derive these properties from use cases, and to deploy a DT as an interacting component in IIoT platforms.

First of all, the term digital twin is misleading. Although biological twins exhibit many genetic matches and start from a common environment, they evolve and socialise largely autonomously and independently of each other, at least with increasing age. Conversely, the "socialisation" and lifetime of a DT, especially in a digital factory, is basically independent of that of its real-world counterpart. Instead, the properties that are required depend upon the use cases and their associated lifetime phase of the DT as described below.

In design and engineering departments, digital representations of physical assets are created in virtual environments which are becoming ever closer to reality. A robot arm may be simulated in its cooperation with other robot arms or humans and optimised in its behaviour even before the physical robot arm is produced and installed.

In production environments, the ideal DT should comprise an exact image of all the properties and functions of the physical component (e.g. a robot arm or a pressure sensor), synchronised in (near) real-time throughout its life. Winding time back and forth would enables analysts to evaluate past situations and simulate future scenarios by means of prognostic models. Furthermore, an operation upon a DT should instantly affect the physical component and vice versa. Today's technologies such as embedded sensors, the Industrial Internet of Things (IIoT) [1], efficient machine-to-machine (M2M) communication as well as cost-efficient and scalable data storage seem to make this type of synchronisation possible.

Long after the life of the physical object has come to an end, e.g. due to wear or

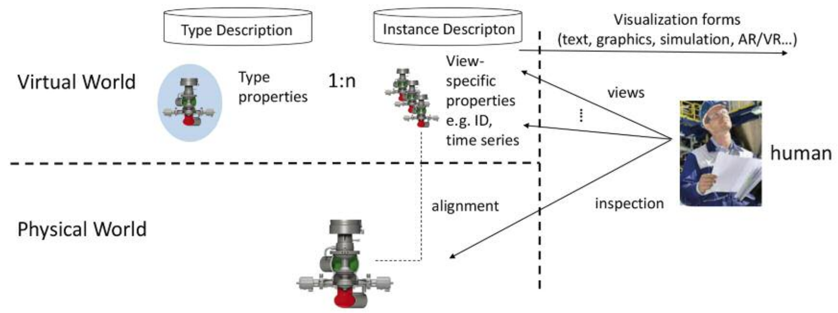

Figure 1: Basic Concept of a Digital Twin (simplified). © 2018 Usländer, Fraunhofer IOSB.

dismantling, the DT may still exist, however, the archiving may be restricted to those properties that have a long-lasting value for documentation purposes.

All these use cases require different sets of DT properties that may, however, be expressed as different views upon an overarching set of properties.

There is a huge problem of DT interoperability when linking use cases and, hence, DT views and DTs among themselves. The digital model of an operating machine in a production control system, in addition to identification data, comprises only those machine status and operational data which are relevant for an operator. Engineering data describing type and geometry are typically not accessible or directly usable for production control systems. Incompatible IT systems and data models as well as different semantics hinder integrated industrial analytics and DT property value exchange.

In order to overcome these interoperability problems DTs need to follow standards (e.g. agreed property definitions and thesauri such as the cross-industry master-data ISO/IEC standard eCl@ss for products and services) and a dedicated engineering methodology. DTs shall be designed and implemented as reusable software components (e.g. Industrie 4.0 components [2]) being deployed in IIoT platforms and made accessible via interaction protocols and services based upon international standards [3]. Industry 4.0 components comprise an asset administration shell (AAS) and its asset counterparts, and are deployed within an IIoT platform environment. The AAS distinguishes between sub-models that are determined by application domains, industrial sectors and their standards, and views that are defined by the functional and informational shell of those properties that are required by the intended use cases.

When engineering DT as I4.0 components, a two-sided approach is required. From top-down it is important to know which properties are required by which use case. From bottom-up it is essential to know which I4.0 components are already specified or deployed in IIoT platforms and may be reused or refined. Fraunhofer IOSB provides a methodology known as SERVUS (service-oriented design of information systems based upon use case specifications) which supports such a two-sided analysis and design methodology and implements it in a Web-based collaborative platform engineering information system [4]. SERVUS allows an analyst to specify and document use cases as semi-structured tables, break them down into requirements of I4.0 components and map them in an agile manner to specified capabilities of I4.0 components of existing and emerging IIoT platforms. It helps to mediate between the possibly conflicting demands of users, product managers, software engineers and technology experts. The SERVUS methodology is indispensable for engineering interoperable digital twins to be deployed in IIoT platform environments.

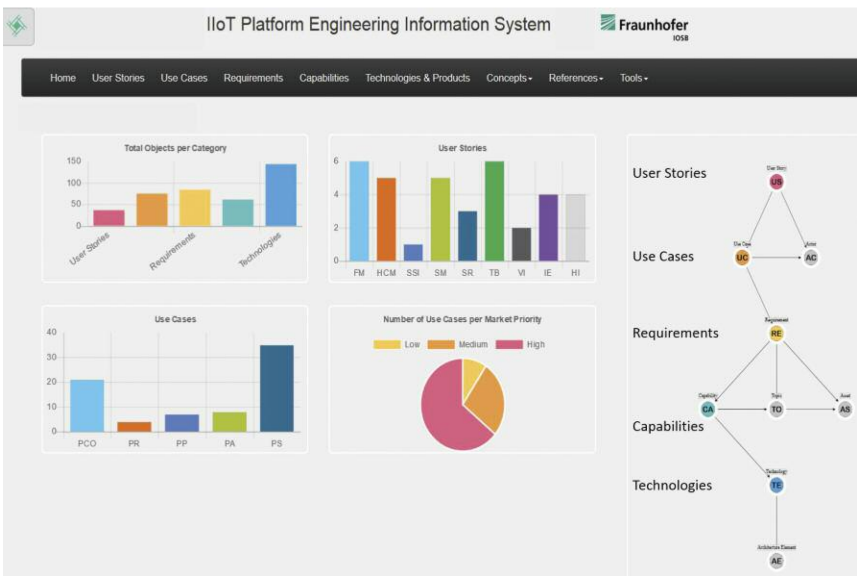

Figure 2: Dashboard of the IIoT Platform Engineering Information System based upon SERVUS. © 2018 Usländer, Fraunhofer IOSB.

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Deploying Digital Twins in a Lambda Architecture for Industry 4.0

by Jacopo Parri, Samuele Sampietro and Enrico Vicario (University of Florence)

The JARVIS project (Just-in-time ARtificial Intelligence for the eValuation of Industrial Signals) exploits a domain logic of digital twins to connect the IoT layer with enterprise scale components in a Lambda architecture for Industry 4.0.

In the agenda of industry 4.0, connection of low level sensors and actuators with enterprise scale components is a key enabler for horizontal and vertical integration, driving the shift towards smart factories and processes. [1]

The JARVIS project [L1] realises a framework supporting development, operation, and maintenance of industrial systems through the integration of enterprise scale information systems and processes with physical components equipped with telemetry and actuation capabilities. In this scenario, digital twins provide a digital replica of remote physical devices, modeling resources and processes through a software representation in which they are implemented as entity objects of a domain, reconciling the needs of different levels of abstraction and control.

The JARVIS project is co-funded by the Tuscany regional government (Italy) in the POR FESR 2014-2020 program and developed by the industrial PMI partners LASCAUX, SISMIC SISTEMI, JAEWA, and BEENOMIO, with the scientific support of the labs of Software Technologies, Artificial Intelligence, and Global Optimization of the University of Florence.

The general purpose of the project is to design and develop an hardware/software architecture, enabling efficient management of industrial devices, planning and scheduling of predictive maintenance tasks, and offline or real-time analysis of assets. A prototype implementation will be tested over a concrete operative scenario, demonstrating its application in the real case of road control systems.

JARVIS aims to:
- develop a domain logic that supports agile creation of digital twins through the Reflection architectural pattern;
- develop a Lambda architecture using digital twins to connect the IoT layer with enterprise scale components and data analytics;
- integrate an ecosystem of chatbots, intended as software systems (i.e. bots) capable of sustaining a dialog (i.e. chat) with autonomy and intelligence, to support mediation and inversion of responsibility in the interaction of users with digital twins and data analytics, and also to enhance customer care services and operations management services developed by LASCAUX and BEENOMIO;
- integrate a plurality of data analytics developed by the University of Florence, applying advanced methods of machine learning, optimization, and stochastic modelling that supports just-in-time maintenance and advanced interaction with users involved in operation processes;
- undertake the joint development of a reusable framework, validating it in in the real case of speed control and access regulation to limited traffic zones (ZTL) of some Italian municipal authorities, with the know-how of SISMIC SISTEMI.

Digital Twin in the JARVIS architecture

The core component of the JARVIS architecture is a domain logic hosting digital twins of physical devices and their compositions, based on a combination of the Composite design pattern and the Reflection architectural pattern [2] (see Figure 1), which provides a way to represent hierarchical aggregations and also offers a mechanism to modify dynamically at runtime the structure and the behaviour of a software application, splitting the domain logic into two parts, one reflecting the other.

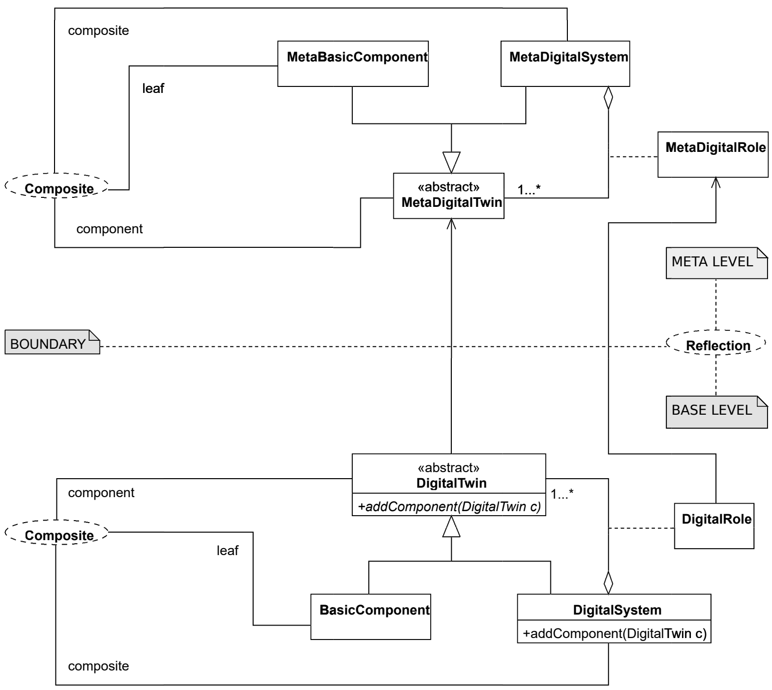

Figure 1: UML class diagram of digital twins, modelled for the JARVIS project, showing the combination of Reflection and Composite design patterns. As a result one DigitalTwin instance can model both a single physical device, if it is a leaf (i.e. BasicComponent), or a composite system, if it is an aggregation of many sub-components (i.e. DigitalSystem). The association class DigitalRole is useful to distinguish between children components of the same type that contribute to the same higher level system.

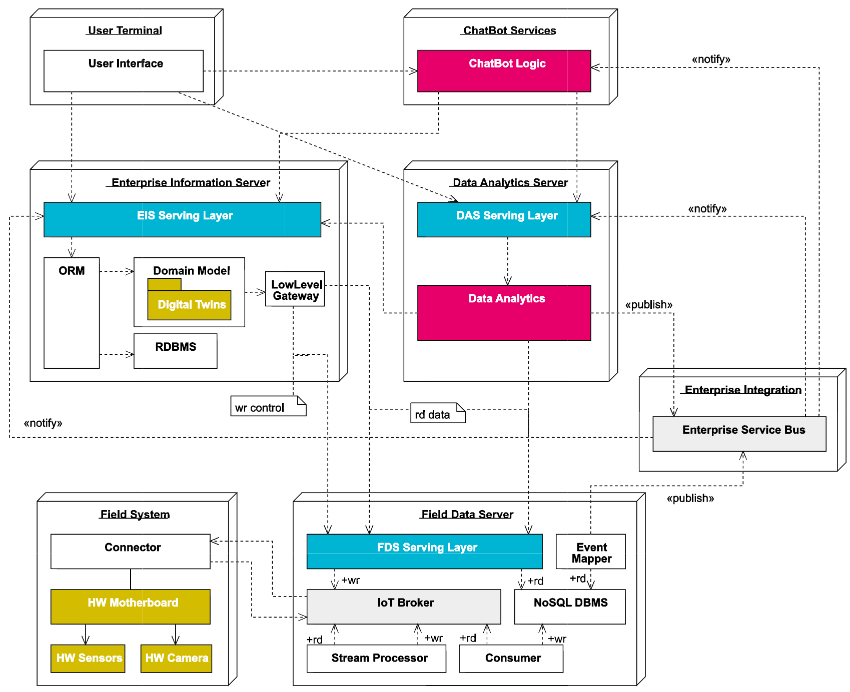

Figure 2: Deployment of digital twins in the JARVIS architecture.

According to the Reflection pattern, the base level defines the logic, exploiting the hierarchical and composite structure of digital twins; while the meta level describes types, relations, structures, statuses and behaviours of the base level, defining the hierarchical conceptual structure of installed field devices.

Digital twins are deployed at the core of a Lambda architecture [3], designed so as to promote fault-tolerance, high-levels of data ingestion, adaptability, and deployability (see Figure 2). The overall system is organised as a composition of distributed sub-systems, whose tasks and responsibilities are characterised as follows:

- a field system instance is responsible for acquiring and generating IoT data flows, sampled by a physical device during its operating lifetime (e.g. a ZTL gate with camera and sensors). Each relevant field system is associated with a digital twin, modelled into the domain logic of the enterprise information server (EIS);
- IoT data streams are transferred to the field data server (FDS), through an IoT broker, which filters and synthetizes them, just before storing as raw data inside a NoSQL DBMS. This sub-system accomplishes the role of speed layer, being responsible for big data ingestion;
- some of the persistent raw data could be manipulated and sent in push mode to any other sub-system through an enterprise service bus (ESB), which implements the publish and subscribe enterprise integration pattern (EIP), enabling communications between sub-systems within a scalable and decoupled infrastructure;
- the EIS implements the batch layer: a digital snapshot of device status (i.e. digital twins instances) is stored in a long-term consistent DBMS, receiving and adapting fine-grained data coming from the FDS;
- context interpretation and processing are delegated to a swarm of autonomous and independent agents that interact with digital twins, enabling descriptive, predictive and prescriptive analysis, through machine learning mechanisms and stochastic model techniques (e.g. predicting or detecting a malfunction of the ZTL gate in order to restore the field device). These agents are implemented inside the data analytics server (DAS), following a micro-services architectural style;
- the serving layer proposed by the Lambda architecture is designed over many sub-systems (i.e. FDS, EIS, and DAS), which expose data in different levels of granularity via REST services, enabling the implementation of a wide variety of clients.

The system allows both push and pull duplex communications among human operators and physical devices, realising a sort of inversion of responsibility that enables just-in-time maintenance of industrial plants. At the base, an ecosystem of chatbots has been designed to supply an instant messaging platform with a smart and dynamic behaviour.

Conclusions

JARVIS has been designed to manage data and informations in different degrees of variability, volume and speed; thus, it is possible to consolidate low granularity data streams, originating from IoT devices, into high granularity data at rest, through the abstraction of Digital Twins and Lambda architecture. Every sub-system, during its lifecycle, could have very different times and paces of maintenance; indeed, while DAS and UIs are supposed to change very often, EIS should have sporadic mutations and adaptations. To meet these requirements, a fundamental role is played by the reflective nature of the Digital Twins, which enables to modify types and behaviours of the domain logic, without re-coding or re-deploying each sub-system.

Link:
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The Digital Twin – An Essential Key Technology for Industrie 4.0

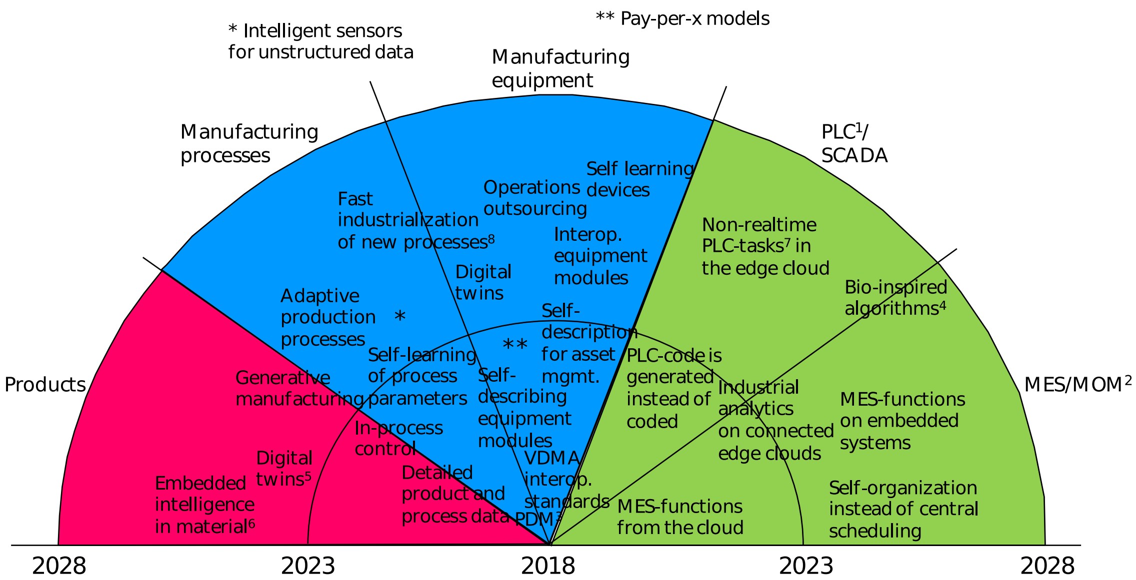
by Olaf Sauer (Fraunhofer IOSB)

Together with colleagues from the Fraunhofer Industrie 4.0-community Fraunhofer IOSB is working on a definition of digital twins and on use cases that show their benefits. A Fraunhofer whitepaper is under work, where we take into account various aspects of digital twins such as material science, product development, manufacturing process development, digital factories, manufacturing operations and reference architectures. In this paper we describe some general aspects of digital twins and illustrate the concept with some examples from companies that have been early to adopt the concepts of digital twins.

Currently the digital twin (see Figure 1) is one of the emerging technologies in discussion in several domains; it is a concept of modelling assets with all geometrical data, kinematic functionality and logical behaviour using digital tools. The digital twin refers directly to the physical asset and allows it to be simulated, controlled and improved. According to Gartner today less than 1 % of physical machines and components "are modelled such that the models capture and mimic behaviour" [1].

Currently digital twins are discussed in Industry 4.0-working groups when talking about the asset administration shell [1] or industry 4.0-components. From our point of view, the digital twin will become a major topic for research in the coming years, because digital twins are not single objects or monolithic data models, but are composed of different aspects of digital representations, functionalities, models, interfaces etc. From a manufacturing and its engineering perspective, it is evident that digital twins perform different tasks, such as:

- Self-description using unique attributes and parameters describing configuration data, e.g. for auto-identification, to connect machines and components easily to MES and other Industrial IoT-solutions [2].
- Description of skills, including parts of control code leading to the result, that an assembly of components and their respective parts of control logic fit to a finally running control program. This leads to a PLUGandWORK, allowing for plugging in new components at runtime, and integrating them automatically on a functional level [3].
- Models of the correct runtime behaviour of a machine, a line or an entire manufacturing shop, based on learned data from machine learning.
- Offline- and online-simulation including the very different types of simulation such as finite element simulation, virtual commissioning or physics simulation in which produced goods interact with machine kinematics. Ideally, different simulation models must be able to interact to come to an integrated simulation model. Up to now, one of the main uses of the digital twin has been for simulation; as we point out here, this definition is much to narrow.
- Digital factory describing machines and other manufacturing resources, buildings and utilities. Building information model (BIM) might also be part of a digital twin as long as it contains relevant information, e.g.



¹PLC: Programmable logic controller
²MES: Manufacturing Execution Systems
MOM: Manufacturing Operations Management
³PDM: Integrated product- and process data management
⁴SFB 89 „Invasive Computing" in Industrial Automation
⁵SFB136 "Funktionsorientierte Fertigung auf der Basis charakteristischer Prozesssignaturen"
⁶SFB 653 „Gentelligente Bauteile - Neue Wege in der Produktionstechnik"
⁷Virtual PLCs, see e.g. project pICASSO
⁸ see www.forschungsfabrik-ka.de

Figure 1: Fraunhofer-internal research results for manufacturing related technologies.

topology. The concept of digital factories already has a long history and is described by well-known standards, such as VDI 4499.
- Services that a cyber-physical component offers to its users.
- IT security, access rights, handling of certificates, version management and compatibility checks of different versions of digital twins [4].

For Industry 4.0 and the digitisation of manufacturing digital twins are essential. Their content must be used through different stages of the lifecycle, within different types of platforms and various tools, from engineering to after sales services. The following use cases already show the potential benefits, e.g., to optimise products and processes almost during runtime:

1. Automation supplier WAGO has developed an approach called DIMA (decentralised intelligence for modular equipment), enabling modules from different vendors to be integrated into a final production system. Its core is the Module Type Package (MTP), a kind of self-description of the modules. The MTP can be accessed through an interface and contains communication parameters, functional production services that the module offers to the entire production system and information for the production monitoring system.
2. Components from FESTO are described as AutomationML-models including geometry, kinematics and software. They also refer e.g. to EPLAN schematic services, which are FESTO-built Macro-libraries for EPLAN Electric P8, V2. The components also store data from the application and from operations, pre-process the data according to VDMA 24582 in CODESYS V3 and transfer these information further on to a cloud.
3. Each HOMAG-machine for manufacturing wooden work pieces has its own asset administration shell including a proprietary XML-description and an OPC UA-communication. Homag offers machine related services, e.g. the diagnosis system woodScout including an integrated machine documentation, via a cloud connector from the Homag owned Tapio-Cloud, based on Microsoft Azure. Homag's customer Nobilia, a producer of kitchen furniture, uses the Homag digital twins to demonstrate a virtual customer specific production of lot size 1.

From these first examples it is crystal clear that the application of digital twins will be very specific and always according to the use case; however, it must be possible to integrate the different part models of the digital twins easily based on their unique description.

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Motion-Structural Analysis of Systems through Digital Twins

by Sebastian Haag and Reiner Anderl (Technische Universität Darmstadt)

Digital twins enable the analysis of systems under real world conditions using multiphysics models, sensors and bidirectional data connections between the digital and its physical twin. At the research lab of the Department of Computer Integrated Design (DiK) of Technische Universität Darmstadt, a digital twin demonstrator was developed that enables a real-time motion-structural simulation of a bending beam test bench. The approach provides proof of many of the publicised benefits through a comprehensible digital twin system.

Digital twins constitute virtual representations of physically existent systems. The exchange of data between digital and physical twin takes place through bidirectional data connections. The networking of technical systems, also called cyber-physical systems (CPS), is one of the key tasks of the digitisation of industrial production, which in Germany is being promoted under the term Industrie 4.0. CPS use embedded electronics, software, sensors, actuators, and network connectivity to collect, process, and communicate data about their condition or behaviour over wired or wireless networks. The ability to communicate allows the synchronisation of physical and virtual space and thus forms the basis for the creation of digital twins. The transmitted data regarding state, behaviour, or environment serve as input to multidimensional, physical models that make up the digital twin. The use of physical data collected by sensors in real space enables digital twins to analyse and simulate real conditions, to respond to changes, to optimise the operation of the system, and thus generate added value for the product usage phase. The processing of the data is hereby not accomplished using classical methods of data processing, but with methods of computer-aided technologies (CAx). The aim of this project is to demonstrate the application of digital twins using a

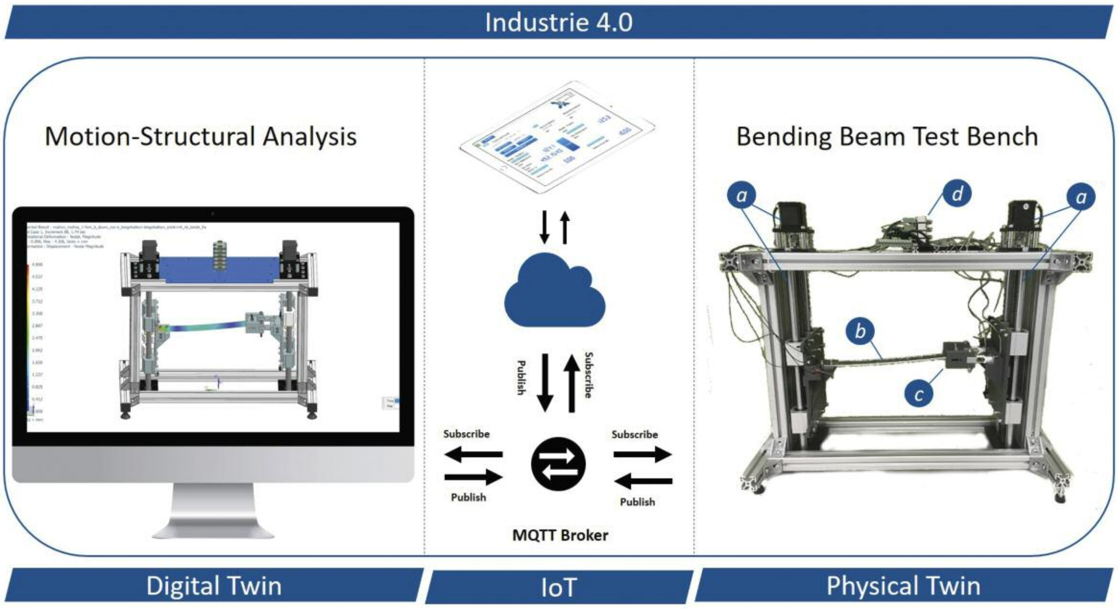

Figure 1: Schematic of demonstrator architecture. Physical and digital twin are connected via MQTT broker with each other and an IoT platform. Both twins can be controlled from any internet capable device. The test bench consists of: linear actuator on each side (a), bending beam (b), load cells (c) and control unit, microprocessor and network interface (d).

cyber-physical bending beam test bench connected to a motion-structural model of the system, its digital twin. The demonstrator is located at the research lab of the Department of Computer Integrated Design of Technische Universität Darmstadt [L1] but can be accessed via a secure connection by any internet-capable device from anywhere in the world.

In step one of phase one, a simple bending beam test bench was developed. The bending beam was chosen because its physics are easily comprehensible thus making it ideal to demonstrate the potential of digital twin technology. The test bench (see Figure 1), the physical twin, consists of two linear actuators (a) in between which the bending beam (b) is clamped. Two load cells (c) are integrated into the holding fixture on one side to measure the resulting force. The displacement is calculated as the difference between the actuator positions. The control unit (d) is set atop the frame. In step two, the mechatronic test bench was transformed into a cyber-physical system by adding a microprocessor and a communication interface and connecting it to an Internet of Things (IoT) platform using the MQTT messaging protocol. Through a dashboard on the IoT platform, the linear actuators can be controlled and the sensor data can be visualised on any authorised device connected to the internet. In step three, an isolated finite element model of the bending beam was modelled and also connected to the IoT platform through the application-programming interface of the CAD-system. At this point, a human user could run a bending beam test through the dashboard on both the physical system as well as the digital twin using only a smartphone. The methods and results of this first phase are published in [1].

In phase two, a motion-structural analysis model of the entire test bench was developed. Motion-structural analysis combines the process chains of multi-body simulation (MBS) and finite element analysis (FEA). MBS calculate the dynamic movement of an assembly and are used to determine motion sequences, joint positions and collision areas under the consideration of the physical constraints. Originally, in MBS the elastostatics of individual components are neglected. However, in motion-structural analyses, the motion simulation calculates reaction forces and loads on the individual components, which then serve as input into a structural FEA. The additional chaining provides more accurate component strength results than pure FEA under self-defined load cases and increases the understanding of the performance of components in their operating environment. The motion-structural model was similarly connected to the IoT platform. The operator can now control the actuators individually and the digital twin will mirror the behaviour of its physical twin as well as visualise additional data, such as actual stress and deformation characteristics during usage. At present, the real-time capability of the entire system is limited by the performance of the workstation running the motion-structural simulation.

The demonstrator is part of the project "Smart Components within Smart Production Processes and Environments (SCoPE)" within the Brazilian-German Collaborative Research Initiative on Smart Connected Manufacturing (BRAGECRIM) [L2] funded by DFG. Other institutes involved in this project are the Laboratory for Computer Integrated Design and Manufacturing of the Methodist University of Piracicaba and the Department of Production Engineering of the Polytechnic School of the University of Sao Paulo.

Links:
[L1] https://kwz.me/hdo
[L2] https://kwz.me/hdO

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Digital Twin Assisted Human-Robot Collaborative Workcell Control

by Tamás Cserteg, Gábor Erdős and Gergely Horváth (MTA SZTAKI)

Multiple, linked research projects on the topic of human-robot collaboration have been carried out in MTA Sztaki with the aim of developing ergonomic, gesture driven, robot control methods. Although robots are already used in many different fields, the next generation of robots will need to work in shared workplaces with human operators complementing and not substituting their work. The implementation of such shared workplaces raises new problems, such as security of the human operator and defining simple and unambiguous communication interface between the human operator and the robot. To overcome these problems a detailed, up-to-date model, i.e., a digital twin, has been created.

To achieve our goal of defining a communication interface between human and robot, we first needed a high level method to monitor the actual state of the robot as well as the present operator(s), and to this end we created the digital twin of our workcell, which consisted of a Microsoft Kinect sensor, version 2, a UR5 robot, and a human operator. For the twin to be usable, it not only has to be loaded with real-time data, it must also be properly calibrated. Once calibrated, the data from the digital twin (e.g., the position of the operator in the past) can be used for human gesture recognition, which can be used to control the robot.

Once we'd created and calibrated the digital twin we were able to perform a simple hand-over scenario between human and robot, implementing gesture communication, the details of which are summarised below.

Digital Twin

The base of system is the digital twin, which is a digital representation of a workcell, containing as much information about it as possible. It includes the current states of the various equipment (robots, production or warehouse units etc), sensor data and even related database connections. Figure 1 shows a partial visualisation of the digital twin: a digital model extended with measured point cloud data.

Near real-time updating of the digital twin is crucial, so the digital twin should provide the same information as the real world workcell would. The digital twin can be used as a centralised source of information, or it can be used to boost the amount of available information. It can be also be used to implement virtual sensors by applying the necessary calculation on the digital twin. It is also possible to check the potential outcome of a given command, by running simulations on the digital twin. Furthermore, if the simulation is fast enough, it may also be used as feedback in the control loop. The digital twin of the workcell, shared by humans and robots, is modelled as a linkage, which is capable of capturing the geometric and kinematic relations of the static and moving objects.

Calibration

Usually the calculation of joint and link dimension errors of robotic arms is considered as calibration, which corresponds to precise pick and move scenarios. On the other hand, calculation of transformation between the local reference frame and some pre-defined global reference frame can also be viewed as calibration. Throughout our work and in the referenced paper we consider the latter definition. This will give an accurate virtual model—the digital twin itself—that contains the current, updated state of the workcell, capable of serving as an input for any kind of workcell control. Calibration tasks can be daunting, time consuming and labour intensive. In our work (presented in [1]) we aimed for a solution that was both as modular and automated as much as possible. Automatisation is key: it both improves the precision of the calibration by eliminating human errors, and

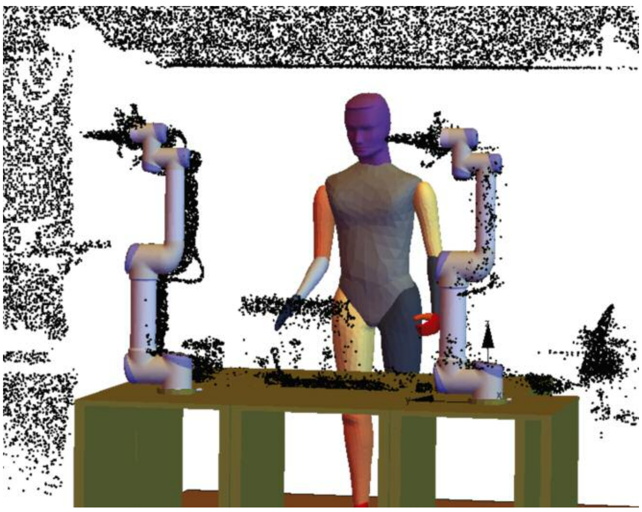

Figure 1: Virtual model extended with measured data.

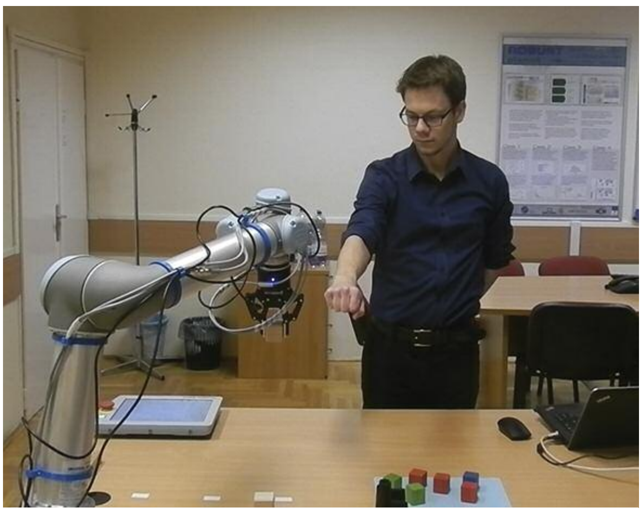

Figure 2: Hand over in action.

liberates the human operator from a time-consuming task. On the other hand, modularity is vital when gluing together various modules.

Virtual Sensors

In the implemented use-case in [2] the operator controlling the robots—the one closest to it—has to be chosen. To choose the right person, the distance of every human operator from both robots has to be measured. It would be a challenging task to make these measurements in the real world with actual sensors, so virtual sensors are applied that perform the task at hand. With the aid of the virtual sensors we are able to make the distance measurements in the virtual model, find the closest operator for every robot and find their ID, which can be sent back to the processing algorithm. The use-case explained demonstrates the possibility of integrating virtual sensors in the digital twin of a workcell. While distance measurement was used to find authorised personnel by its position to operate the robots, virtual sensors have the potential for diverse utilisation, for example the virtual model can be extended with colour data, making it possible to recognise QR-code stamps or even faces of the operators, or it is possible to use virtual sensors to measure the velocity or acceleration of the robots, without actually encumbering potentially low capacity equipment.

Gesture Recognition

Gesture recognition is the mathematical formulation and capturing of human motion, using a computational device. From the global coordinates of the human joints (returned by the official Microsoft Kinect SDK) the positions of the bones constructing the human operator are calculated, as the posture of the bones is the basis of the recognition. The angular position of bones in relation to other bones, and global angular positions of bones compared to the global axis, form the basis of the clustering gesture recognition.

Gesture Communication

During any kind of cooperation be it human-human, human-robot, or even robot-robot, the participating entities have to be able to communicate with each other in a way that is unambiguous. When a human is participating in the interaction it is also important to make the communication as comfortable and natural as possible. As two-thirds of human communication is non-verbal, special robot movement patterns can be used to communicate its state to the worker. With the gesture control this bilateral information transition is what we call gesture communication, and special patterns have been created to signal multiple state changes. In paper [3] we implemented a robot-human tool handover scenario, where the operator can take the tool at any arbitrary position. The robot follows the hand of the operator and distinguishes between movement and intention to take the tool from its gripper. Gesture communication was used to signal the robot's state to the human operator.

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Inria Project Lab “AVATAR: The Next Generation of our Virtual Selves in Digital Worlds”

by Ludovic Hoyet (Inria)

In years to come, the development of new immersive media (including digitalisation of industries) will lead to a massive spread of avatars, the users' representation in the virtual world. By leveraging the complementary expertise of six Inria teams, the project “Avatar” aims to design the next generation of avatars for digital worlds in order to reach new levels of user embodiment in and through their virtual replica.

Owing to the massive dissemination of consumer-grade head-mounted displays, the development of novel immersive media is speeding up the process of digitisation, in domains ranging from entertainment industries, to sports and industrial training simulations, and medical cybertherapies. In such applications, modelling easily and efficiently the virtual counterpart of physical products or processes, i.e., the digital twins, is therefore becoming increasingly crucial. In particular, with the development of HMDs, users do not see their physical body. Therefore, the representation of users in the virtual world, i.e., their avatar, is now becoming a major requirement for making people live a truly immersive and effective experience, and raises questions about how well users can be embodied in their avatars, a concept called the “sense of embodiment” [1]. While both the visual aspect and motor capabilities of avatars have been shown to affect the ability of users to embody in avatars [2], they still often fail at conveying a strong sense of embodiment or interaction. This failure can be explained by current technological limitations in acquiring, simulating and controlling avatars, but it is also largely due to a lack of perceptual understanding about how we perceive and interact with avatars.

The objective of the Inria Avatar project is to expand the limits of perception and interaction through avatars in immersive media. In particular, we believe that the next generation of avatars will need to provide a stronger sense of embodiment in order to enable natural and expressive interactions with virtual worlds, to better feel the digital content by means of multisensory feedback, and to better share virtual experiences. Such objectives raise multiple scientific challenges, e.g.: How to acquire and model faithful or stylised representations of the users? How to render and animate them in highly expressive or symbolic ways? How to enable complex 3D interaction capabilities? How to design and identify the best means of conveying multisensory information to users through their avatar? To address these multidisciplinary challenges, we are bringing together the complementary expertise of six Inria teams at all levels [L1]: Graphdeco (Rendering,Inria Sophia Antipolis Méditerranée), Hybrid (3D Interactions and Virtual Reality, Inria Rennes Bretagne Atlantique), Loki (Human-Computer Interaction, Inria Lille Nord Europe), MimeTIC (Animation and Biomecanics, Inria Rennes Bretagne Atlantique), Morpheo (Computer Vision, Inria Grenoble Rhone-Alpes), Potioc (Human-Computer Interaction, Inria Bordeaux Sud-Ouest). Our scientific challenges are also strongly interconnected with fundamental knowledge in perception, psychology and neuroscience, addressed in collaboration with our partner Prof. Mel Slater (University of Barcelona), world expert on fundamental psychological and neuroscience aspects of "virtual embodiment".

The general philosophy of this project, which started in May 2018, is to develop the next generation of avatars by using a multidisciplinary approach to address complex problems related to the acquisition, rendering, animation, and multi-sensory feedback and interactions envisaged for avatars, while characterising the perceptual experience and the resulting sense of embodiment across the whole pipeline. While the benefits of creating interactive and embodied avatars can be demonstrated for numerous domains of applications, ranging from entertainment, to training, education or health, our project focuses on two key demonstrators: avatars for immersive cinema, in collaboration with our industrial partner Technicolor, and avatars for industrial training, in collaboration with our industrial partner Faurecia. Even though different use-cases will require specific assets and demonstrators, our goal is to ensure that they will rely on the same core technological output to allow for their use in new application domains in the future.

This unique opportunity to bring together all the scientific and technological expertise needed to cover the entire technical pipeline as well as the necessary perceptual/psychological perspective of "virtual embodiment" should enable the creation of the next generation of avatars. By making it easy to use virtual representations of users in the majority of immersive applications, ranging from home to industrial setups, we believe that avatars should become an effective tool truly creating new industrial and entertainment challenges and applications, as well as fostering novel multidisciplinary collaborations with international academic and industrial partners.

The Inria project "Avatar" aims to design the next generation of avatars for digital worlds in order to reach new levels of user embodiment in and through their virtual replica. © Inria / Photo J.C. Moschetti.

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Simulating the Physics of Fluids on a Computer

by Bruno Levy (Inria)

Research teams at Inria and University Paris Sud are elaborating new mathematical methods to simulate the physics of fluids. This has the potential to improve a crucial component of digital twin technology.

Digital twins can dramatically reduce the development cost of complex systems by making it possible to test different designs in a very short time, or by simulating the behaviour of the system in various conditions. A central component in digital twin technology is the set of methods that can accurately simulate the laws of physics in a computer. As such, fluid dynamics play an important role in many different systems, from cars to spaceships, from the most sophisticated turbo-machine to (seemingly) simpler objects, such as car tires, designed to best evacuate water and optimise adherence on a wet road.

Fluids are objects that are notoriously difficult to simulate for various reasons, including both their geometries and the underlying physics:
- Shape and topology of interfaces: during its movement, a fluid can show drastic changes in shape and topology. The free surface of a fluid can split and merge, create splashes. When considering two non-miscible fluids (water and oil), the interface between both fluids can form complicated shapes;
- Incompressibility and conservation of physical quantities: it is well known that some quantities are conserved, the most obvious one being mass. The kinetic energy is also conserved, as well as momentum, and another vector quantity that corresponds to the way things are spinning (called "angular momentum"). If considering an incompressible fluid (like most liquids), then the volume of a fluid element needs to be conserved as well. These conservation laws are not trivial to enforce in a numerical simulation.

Newton's first law states that an isolated particle moves along a straight line with constant speed. In a fluid, the particles try to follow trajectories that are as straight as possible, but in addition they are subject to both gravity and the incompressibility constraint. The theory of things that move in as straight a line as possible while satisfying a constraint (geodesics) has for the incompressibility constraint a rich and elegant mathematical structure [1] that can be transformed into a computer algorithm. In this computer algorithm, the fluid is decomposed into a set of cells, with cells that follow the movement of the fluid during the simulation (Lagrangian mesh). It is different from most methods that use a fixed mesh through which the fluid flows (Eulerian mesh). This makes it easier to conserve volume and other physical quantities, and gives an explicit representation of the interfaces. It is thus possible to design a computer representation of a fluid that is by design incompressible. In this representation, the fluid is decomposed into a set of cells (close up in Figures 1 and 2). The decomposition is parameterised by

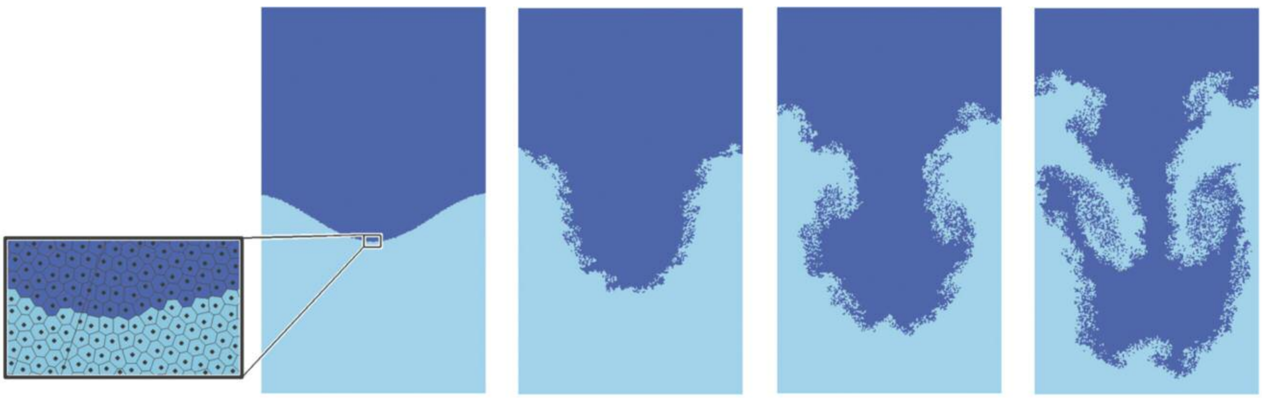

Figure 1: Numerical simulation of what happens when a heavy fluid is put on top of a lighter one: nice patterns of vortices appear, and the fluid becomes more and more turbulent (Taylor-Rayleigh instability).

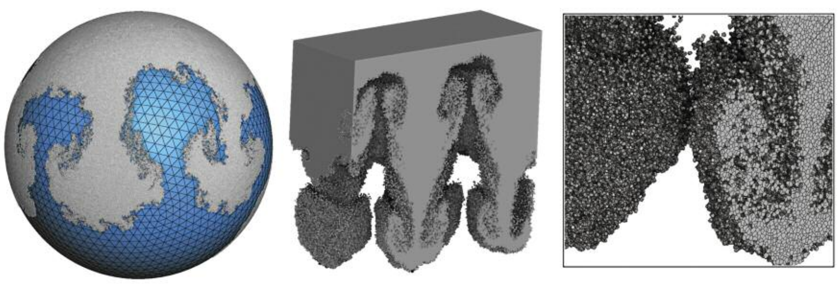

Figure 2: Numerical simulation of Taylor-Rayleigh instability on a sphere (left) and in a 3D volume (right).

a set of points (black dots in Figure 1). Since fluids are incompressible, the cells are supposed to keep the same volume throughout the whole simulation. Enforcing this constraint is a particular instance of a well-known problem in computational mathematics (semi-discrete optimal transport [2]). In cooperation with Quentin Merigot (Paris Sud University), the ALICE/GRAPHYS Inria team develops efficient computational algorithms for solving this problem [3]. This numerical algorithm opens the door to a certain class of fluid simulation algorithms [4].

Figure 1 shows an example of a numerical simulation of what happens when a heavy fluid is put on top of a light fluid. Both fluids try to exchange positions, but incompressibility is a difficult obstruction. At the beginning, pairs of cells manage to exchange their positions (or pairs of atoms when considering real fluids). This gives more room to other cells behind them, and then tiny vortices start to form. These vortices go faster and faster, and larger vortices appear. After some time, the heavy fluid goes to the bottom and the light fluid to the top. More details are given in the course [5] and references herein.

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Mathematical Modelling and Artificial Intelligence in Luxembourg: Twenty PhD Students to be Trained in Data-Driven Modelling

by Stéphane P.A. Bordas, Sundararajan Natarajan, and Andreas Zilian (University of Luxembourg)

To work with digital twins, researchers must have the skills to select and adapt mathematical models to data as it is being acquired. Luxembourg's National Research Fund (FNR) finances the first pan-Luxembourg Doctoral Training Centre in Data-DRIVEN Modelling and Discovery [L1], bridging artificial intelligence with modelling from first principles. The Centre will train the next generation researchers at the interface between computational and data science and application areas ranging from social inequalities to neurodegenerative diseases, through psychology and the science of science. These researchers will lay the foundations enabling digital twinning in a variety of application areas.

Why Computational and Data Sciences: opportunities and challenges

By enabling virtual experiments and computer simulations, scientific computing has become the third pillar of scientific investigation and is central to innovation in most domains of our lives (Rüde et al., 2018). It underpins the majority of today's technological, economic and societal feats.

An upcoming challenge is to harvest the fruits borne by computational sciences in research fields which have not yet benefited from its full potential, e.g. biology, health, the social and behavioural sciences as well as art. Our strategy to achieve this is to leverage the mathematical, procedural and algorithmic commonality between apparently disparate research fields. Achieving this aim will require ever-increasing amounts of data to be harnessed (Ley and Bordas, 2017).

Data-Driven Discovery

Understanding the world, which generates data at an increasing rate, relies on the ability to construct models. To be predictive, or even descriptive, these models must be able to adapt to new information (science model selection, aggregation and adaptation).

We are therefore experiencing a change in paradigm from traditional, hypothesis-driven mathematical models to adaptive data-driven models, which are inherent to the concept of digital twins. Data-driven discovery will become the fourth pillar of science, and the integration of hypothesis-driven and data-driven science concepts is the future of scientific discovery and knowledge generation, by improving decision-making at all levels.

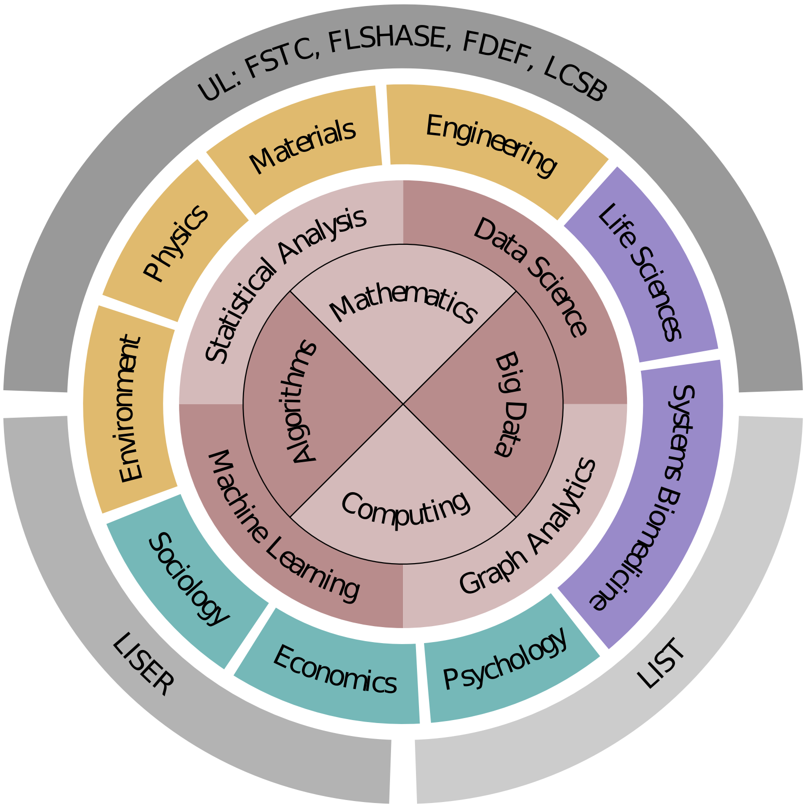
Discovery through data requires integrated data mining, data exploration (interrogation and association), predictive modelling, sensitivity and uncertainty quantification and incorporation of feedback from new or higher quality data.

Methods

Machine learning and statistical analysis are fundamental to address the above issues and enable mapping input to output (supervised) and discovering the structure of input data (unsupervised learning).

Concepts like support vector machines and random forests can be used for pattern recognition. Similar objects are automatically grouped into sets with clustering using k-means, mean-shift or spectral clustering and thereby help with patient cohort segmentation or grouping experimental results. Continuous-valued attributes associated with an object or person can be predicted with regression algorithms like lasso, ridge regression or Gaussian processes. Model selection methods improve predictive models by enabling the comparison, validation and selection of models and parameters using grid search or cross validation.

Methods of dimensionality reduction help to unveil characteristic information hidden in large and/or high-dimensional data sets via principal component analysis, manifold learning or feature selection. Deep learning describes hierarchical learning from data representations by capturing various abstraction levels.



Computational and Data Sciences represent the methodological core common to a variety of data-driven applications targeted by DRIVEN's scientists at leading research institutions in Luxembourg.

Scientific Outcomes and Orientation of the Project

DRIVEN's scientific outcomes are expected to lead to strong novel results in each application domain. Yet, the most exciting scientific achievement brought forward by DRIVEN will be the design of novel multi-disciplinary methodologies. Moreover, the trained research students will become the first interdisciplinary translators able to fuel the third industrial revolution.

Challenges Ahead and Future Activities

The variety and power of machine learning and artificial intelligence techniques are steadily growing. While their ability to describe reality and discover unforeseen patterns in data is clear, our ability to critically evaluate uncertainty and the limitations of these approaches lags behind. More often than not, they are used as black boxes, delivering answers that cannot be easily understood. DRIVEN will investigate these issues by focusing on a few well-chosen fundamental problems in data classification, regression, model reduction and selection.

Ethics

DRIVEN's research directions not only take into account shared technical or methodological similarities of research activities but also the implied ethical and philosophical issues related to the large-scale utilisation of data science techniques. This adds the important ethics co-dimension to the treatment of the addressed research questions and contributes to provoke the intellectual discussion between researchers across the fields by questioning and reflecting on the role of artificial intelligence in law, human labour and social equity.

Partners and ERCIM Collaborators

DRIVEN is led by Computational Engineering and Sciences (Zilian) at the University of Luxembourg in collaboration with Interdisciplinary Centres and the Luxembourgish research centres (LIST and LISER). The team will be provided with supplementary training provided through leading partners including U. Ghent, Inria (France) and ICES (University of Texas at Austin), through a Horizon 2020 TWINNING project (DRIVEN TWINNING).

DRIVEN reinforces complementary initiatives such as Digital Lëtzebuerg and the HPC project of common European interest (PCEI) and Big Data Enabled Applications and reaches out to the European Materials Modelling Council by contributing to the creation of data exchange mechanisms for "digital materials."

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The Netherlands Organisation for Applied Scientific Research Works with Digital Twin in Real Life

by Erik Peeters (TNO ICT Unit)

High-tech equipment companies increasingly use simulations and models to predict the planned requirements of the machines they build. This "digital twin" provides major benefits to the industrial sector, but it seems that model calculations are rarely compared to the end product. The consequence is that development processes and product maintenance are inadequate and that upgrades don't benefit from existing models. The Netherlands Organisation for Applied Scientific Research (TNO)'s Industry 4.0 ambitions support organisations with effective use of models and virtual representations of physical systems to understand, predict, optimise and upgrade their systems and systems behaviour in the field.

With the increasing amount of product variants and "series-of-one" products, it is difficult for organisations to maintain physical setups of any system configuration delivered for necessary maintenance and upgrade tests. At the Netherlands Organisation for Applied Scientific Research (TNO), we support customers with research and numerous testing of digital representation of products, production processes and use phases. Measurements are taken in the final physical production and use process to make digital models more robust. The goal is to create the digital twin of products and enable industries to start production quicker and more flexibly, without delays in the programming or the production of moulds.

TNO ICT Unit, who are we?

Founded in 1932, the TNO's mandate has always been to help governments, universities and companies to benefit from independent applied research and inform them with a demonstrable value on major social and economic issues. The ICT Unit works closely with clients, partners and other TNO units in domains like ICT, telecoms, mobility, logistics, defence, security, high-tech, agri-food, and energy.

Strengthening valuable knowledge for The Netherlands is based on co-working with international and leading knowledge partners and companies. The new membership with ERCIM is a great example of both parties benefiting from exchanging ideas and setting up cooperative international research with other members in the ERCIM community and vice versa.

Scientific Context

It is clear that ICT presents many new opportunities for addressing all kinds of challenges in society. ICT also has the power to fuel innovation and economic growth. The examples are numerous. Traffic safety can improve and traffic jams are reduced with the use of ICT systems exchanging information so quickly and reliably that cars can drive themselves. Ever more people are collecting data on their personal health thanks to smart sensors in mobile devices, applications and software that measure and analyse medical data. Agriculture has higher production with less impact on environment. Breakthroughs in encryption and algorithms are building the foundations for the actual use of the first quantum computers. ICT provides important stimuli for innovation in a broader scientific context than the concrete applications in themselves.

Drawbacks

However, the rapid digital transformation in society is creating new issues of its own. High tech developments like artificial intelligence (AI), the Internet of Things (IoT), big data and independently operating algorithms are becoming increasingly pervasive. Data-driven innovations are important determinants of economic success and societal impact but the distinction between the physical and virtual world is blurring. These developments are giving rise to cyber-physical systems (CPS) in which professionals and consumers interact through augmented and virtual reality interfaces. Secure, transparent, adaptive and robust systems are paramount and necessary for these developments to be successful but also restrained.

Vision

TNO aims to assist governments and businesses in the current complex digital transformation by leveraging its know-how in ICT, policy making and business models. TNO's stakeholders with a focus on product development profit from new opportunities in knowledge and data sharing at an increased efficiency, effectiveness, quality and cost effectiveness. They require fast open infrastructures and trusted digital marketplaces to meet their goals in the new digital ecosystem. Additionally, businesses and societal stakeholders will need to reinvent their business models based on (big) data and the emergence of dominant platforms. This requires laws and regulation that sustain economic benefits and mitigate negative effects, like privacy infringement. In the triple helix combination of universities, applied research, governments, and businesses the economic value of the investments in science is realised. What sets TNO apart is our multidisciplinary approach embedded in a thorough understanding of the application domain with the goal of transforming research into innovation for businesses and governments.

Digital Twin

ICT is also key enabler for innovation in other domains, the high tech equipment industry being one of them. For customers in this sector, TNO has developed the programme "Intensification of Smart Industry" that focuses on the importance of increasing productivity, product development and production technology and services. This includes the perspective of employees and the development of experimental environments in the field lab of the Dutch National Smart Industry Program. This programme contributes to innovations needed to achieve work-learn-innovative environments for life-long learning at all levels and for (vulnerable) groups in industrial environments. From this and other (future) perspectives, TNO is very interested in contributing to the ERCIM Digital Twin Workgroup and is looking forward to creating value with ERCIM members.

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Cross-Organizational Cyber Risk Assessments

by Florian Skopik (AIT)

Cross-organizational cyber risk assessments are the cornerstone of an effective implementation of national cyber security strategies. Only those nation states who know the overall key risks to critical infrastructures and main weaknesses of providers of essential services, can anticipate future cyber security problems and appropriately plan for counter measures. Therefore, the aim of the project CRISCROSS [L1] is to come up with a design and proof-of-concept prototype that enables efficient distributed risk assessments within critical organizations, the timely reporting of findings via an intuitive web platform to the authorities, and the harmonization, aggregation and interpretation of received data at the national level.

The CRISCROSS concept foresees that stakeholders from various organizational levels of critical infrastructure providers are periodically surveyed. As depicted in Figure 1, from technicians to CISOs at the tactical and operational layer up to CEOs at the strategic level, people are asked to rate the relevance of key risks (e.g., lack of business continuity management). For relevant risks, they need to rate how much a risk applies in their opinion to their own organization and whether mitigating actions have been performed (e.g., SLAs, monitoring techniques, third-party assessments etc.). Survey feedback from these different levels of critical organizations across all domains are then collected in a centralized portal. An essential part of the project is the research question on how the surveys are being evaluated, answers weighted and aggregated, and how a big picture can help to create cyber situational awareness [1] within security authorities.

This is an essential step to implement national security strategies and specifically to support NIS authorities in their daily work, since the national supervision of critical sectors is explicitly required by the directive [2]. Thus, authorities have a clear need to anticipate potential consequences if an organization gets hit by a cyber attack. Vital questions, such as if an organization is mature enough to deal with a larger incident on its own, or whether such an incident could affect other organizations need to be answered. Information about risks and the level of preparedness of individual organizations is of paramount importance for national decision making and CRISCROSS clearly provides a substantial contribution to this task.

CRISCROSS Objectives

CRISCROSS is designed to provide answers to three current research questions of nation-wide cyber risk management and in the overall interest of the whole nation state and its authorities:
- First, an objectification of risk analysis approaches should be achieved. Therefore, the CRISCROSS project aims to come up with a method that reduces the dependency on only a few, typically high-level, expert opinions at the

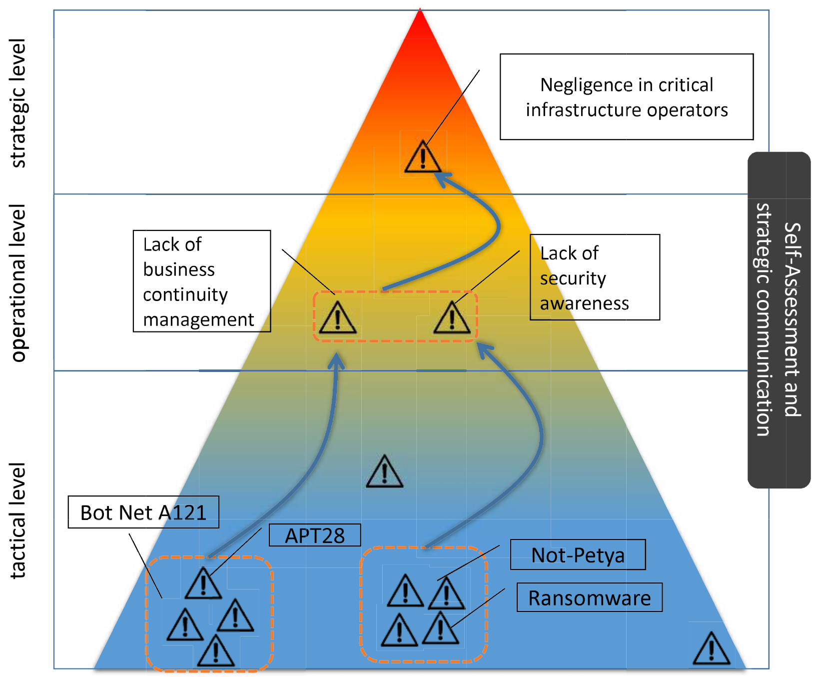

Figure 1: Each organization assesses its risks at three levels and communicates findings to the authorities to create a large-scale situational awareness picture for decision makers.

national layer, but rather collects detailed information directly from the system operators and providers, and aggregates distributed opinions in a sound manner. This is meant to facilitate an objective risk management approach at the national level.

- Furthermore, CRISCROSS works towards an approach to determine adequate indicators to measure the risks in critical sectors, as well as approaches for their measurement and quantification. The aim is to better understand the current and the realistically achievable (compared to desirable) security standards in various dimensions and reliable identify and measure the gap in between. For this purpose, a suitable number of indicators and sources that deliver relevant data in the cyber-security and cyber-risk-related context must be found [3]. Based on this data, a mapping of determined indicators to a functional and technical model that allows to identify the (inter-)dependencies of the investigated companies, is key to a better understanding of the current risk situation across a nation state. In order to create an accurate picture of the current situation with respect to cyber-security and immanent risks, measurements and KPIs in numerous dimensions need to be aggregated.
- Third, CRISCROSS plans to adequately address (near-) real-time demands of a state-wide situational picture. In order to act appropriately upon a current situational picture, decision makers need to have the most accurate data available. Not collecting data on an, e.g., annual basis, but doing it efficiently on a weekly or even daily basis, especially in such a highly volatile area as cyber-security, is a huge challenge on its own and a key aspect of CRISCROSS. Closely related to this is the evaluation of trends and the adequate clustering of risk data across organizations – even if they are of different sizes and situated in different industry sectors.

The Project CRISCROSS and its Consortium

In order to attain these ambitious goals and finally ensure the wide applicability of developed tools and procedures, the project consortium consists of a vital mix of academics with deep knowledge in cyber security (Austrian Institute of Technology, Vienna University of Economics and Business, SBA Research), subject matter experts for the government sector (REPUCO Unternehmensberatung GmbH), practitioners from the software engineering domain (Research Industrial Systems Engineering GmbH) and representatives from the Ministry of the Interior, Ministry of Defence and the Austrian Federal Chancellery. CRISCROSS is an 18-month national research project running from 2017 to 2019 and is funded by the Austrian security-research program KIRAS and by the Austrian Ministry for Transport, Innovation and Technology (BMVIT).

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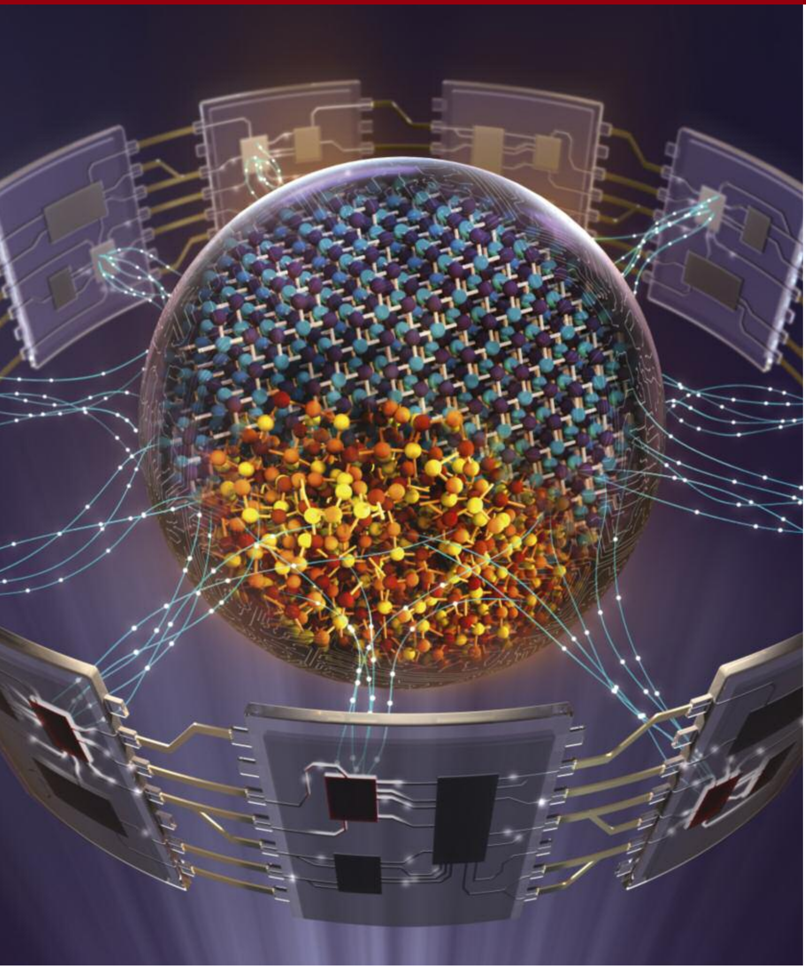

In-Memory Computing: Towards Energy-Efficient Artificial Intelligence

by Manuel Le Gallo, Abu Sebastian and Evangelos Eleftheriou (IBM Research Zurich)

There is a pressing need for energy-efficient non-von Neumann computing systems for highly data-centric artificial intelligence related applications. We have developed an approach that efficiently performs a wide range of machine learning tasks such as compressed sensing, unsupervised learning, solving systems of linear equations, and deep learning.

We are at the pinnacle of a revolution in artificial intelligence (AI) and cognitive computing. The computing systems that run today's AI algorithms are based on the von Neumann architecture which is inefficient at the task of shuttling huge amounts of data back and forth at high speeds. Thus, it is becoming increasingly clear that to build efficient cognitive computers, we need to transition to novel architectures where memory and processing are better collocated. In a first level of inspiration, the idea would be to build computing units where memory and processing co-exist in some form. In-memory computing is one such approach where the physical attributes and state dynamics of memory devices are exploited to perform certain computational tasks in place with very high areal and energy efficiency.

In a conventional computer, the processing and memory units are physically separated. Consequently, a significant amount of data need to be shuttled back and forth during computation, which creates a performance bottleneck commonly referred to as the "von Neumann Bottleneck" (see Figure 1). This physical separation and associated data transfers are arguably one of the main hurdles of traditional computers, as a memory access typically consumes 100 to 1000 times more energy than a processor operation. In in-memory computing, computation is performed in place by exploiting the physical attributes of memory devices organised as a "computational memory" unit. For example, if data A is stored in a computational memory unit and if we would like to perform f(A), then A is not required to be brought to the processing unit (see Figure 1). This is more energy and time efficient than the process performed by a conventional computing system.

However, there are significant challenges that need to be overcome to enable the practical use of in-memory computing for AI algorithms. It is only possible to perform a limited set of operations in the memory units, as opposed to the general-purpose processors that are used in conventional computing systems which can perform any type of computation. Moreover, in-memory computing can only offer limited precision due to the analog nature of the operations performed in the memory units, as opposed to the usual digital computing which can offer arbitrarily high precision (typically 64-bit in conventional computers). These aspects imply a radical rethink in the way an algorithm needs to be designed to solve a certain problem efficiently using in-memory computing.

In the last few years, we have been working towards overcoming those challenges by designing algorithms that can take advantage of in-memory computing hardware to efficiently solve AI related tasks. We have developed prototype in-memory computing hardware based on phase-change memory comprising one million memory cells and aimed at understanding what type of algorithm can be implemented with the set of operations and precision of computation that are achievable with this chip. With this hardware, we were able to successfully demonstrate compression and reconstruction of images [1], unsupervised learning of temporal correlations [2], and solving systems of linear equations with arbitrarily high accuracy [3]. In each of these three applications, we estimate that we achieve energy savings of at least one order of magnitude with respect to using a conventional computer for the same tasks.

One additional application that has been of utmost interest in recent years is the training of neural networks. Deep artificial neural networks have shown remarkable human-like performance in tasks such as image processing and voice recognition. Deep neural networks are loosely inspired by biological neural networks. Parallel processing units called neurons are interconnected by plastic synapses. By tuning the weights of these interconnections, these networks are able to solve certain problems remarkably well. However, because of the need to repeatedly show very large datasets to very large neural networks, it can take multiple days or weeks to train state-of-the-art networks on conventional computing systems. In-memory computing could greatly accelerate the

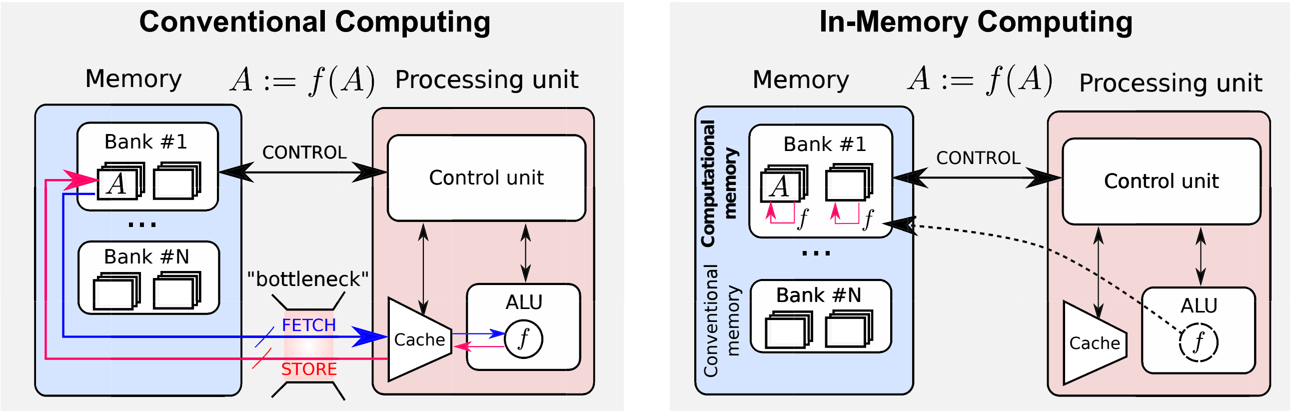

Figure 1: Comparison between a conventional computing architecture (left) and in-memory computing (right). Adapted from [2].

training of neural networks by eliminating the need to move the weight data back and forth between memory and processor.

The key idea in our approach is to encode the synaptic weights as the conductance values of phase-change memory devices organised in a computational memory unit and use it to perform the forward and backward propagation, while the weight changes are accumulated in high precision (see Figure 2). This mixed-precision approach enables training the network to reach high classification accuracy, while performing the bulk of the computation as in-memory computing. Figure 2 shows a simulation result of training a multi-layer perceptron to recognise handwritten digits. The accuracy achieved with our approach is less than one percent lower than that obtained using a conventional computer. Most importantly, the trained weights will be retained in the computational memory for many months or even years without the need to supply any power, thanks to the non-volatility of the phase-change memory devices. A chip trained in this way can be used for inference tasks within sensor devices at a fraction (<1%) of the power that would be used in a conventional computer. More details can be found in our recent paper presented at the ISCAS 2018 conference [4].

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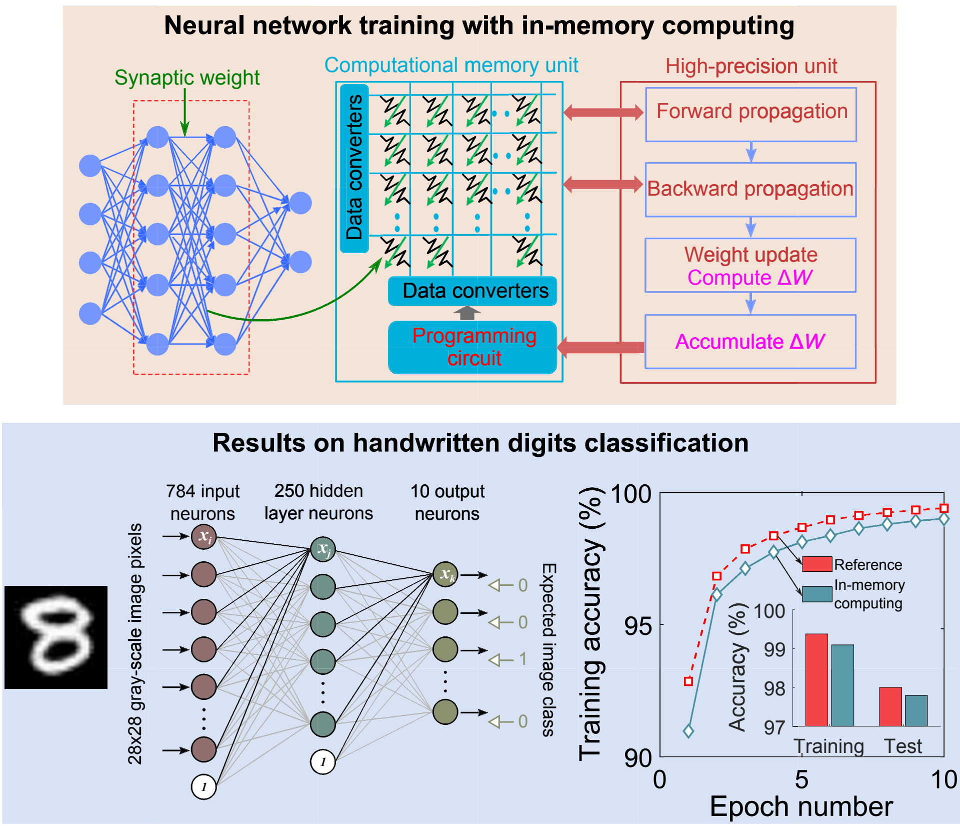

Figure 2: Neural network training algorithm using in-memory computing (top), and simulation results of training a multi-layer perceptron to recognise handwritten digits (bottom). Adapted from [4].

GamECAR: Gamifying Self-Management of Eco-driving

by Aris S. Lalos (University of Patras and ISI ATHENA), Stavros Nousias and Konstantinos Moustakas (University of Patras)

GamECAR is a Euroean project that aims to teach drivers to adopt an eco-friendly driving style through a serious games platform.

Road transport is one of the major causes of the environmental pollution. According to a recent study it is responsible for about 30% on the total emissions of CO2 into the atmosphere [1]. Among the actions individuals can take to reduce their green-house gases associated with personal transportation, there is to operate their current vehicles more efficiently [2], [3]. Recent studies have shown that in certain situations the driver's driving style can result in differences in terms of fuel consumption (and therefore CO2 emissions) from 2 up to 35% between a calm driver and an aggressive one. At this point, it should be also mentioned that numerous studies have underlined the substantial ecological, economic but, also, road safety adverse benefits that can be derived from adopting eco-driving behaviors.

GamECAR aims to develop a highly innovative and interactive Serious Games platform that will empower and guide users to adopt an eco-friendly driving style. This will be achieved, without distracting users from safe driving, through a multidisciplinary approach aiming at the development of a user friendly, unobtrusive multi-player gaming environment, where the users will not only play collaboratively/competitively using their mobile device but also using the car itself and their own bodies, thus turning eco-driving into an immersive and highly motivating experience.

GamECAR platform is partially based on the design and deployment of a sensing prototype, presented in Figure 1, which unobtrusively records physiological, behavioural, environmental and vehicle parameters combined with online and offline data analysis tools that have been developed for the analysis of multi-parametric data, towards the fuel consumption and Eco-Score calculation while links between rewarding gamification elements and the user's driving performance have been also established. A Decision Support System (DSS) has been developed for communicating and presenting eco suggestions to a driver in a tailored, contextualized, timely and safe manner. The aforementioned components have been integrated in an interactive gamified application that have been designed using several game-related design guidelines/elements as means to encourage eco-driving behaviours, presented in Figure 2.

Automotive research and academic organizations with outstanding track records in shaping the future of the Eco-Driving Training (French Institute of Science and Technology for Transport, Development and Networks, Automotive Technology Centre of Galicia and Institute for Transport Studies in Leeds), have joined efforts with experienced researchers demonstrating scientific excellence during the latest years in their respective fields (e.g. AR/VR enabled applications, User Modelling, Data analytics & Decision Support Systems) (University of Patras), a leading company on developing virtual set solutions and Serious Games in

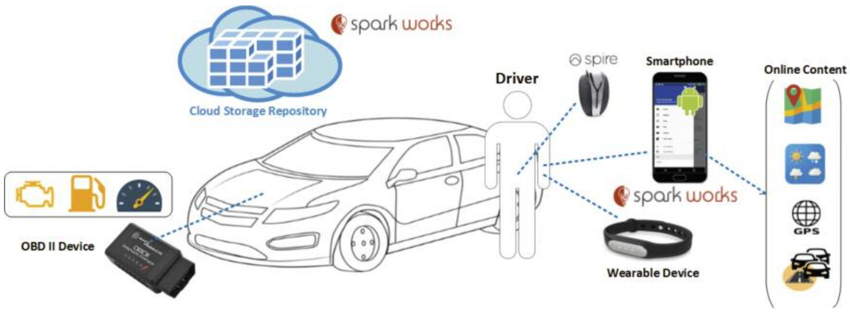

Figure 1: GamECAR data retrieval and processing platform designed by SPARK WORKS.

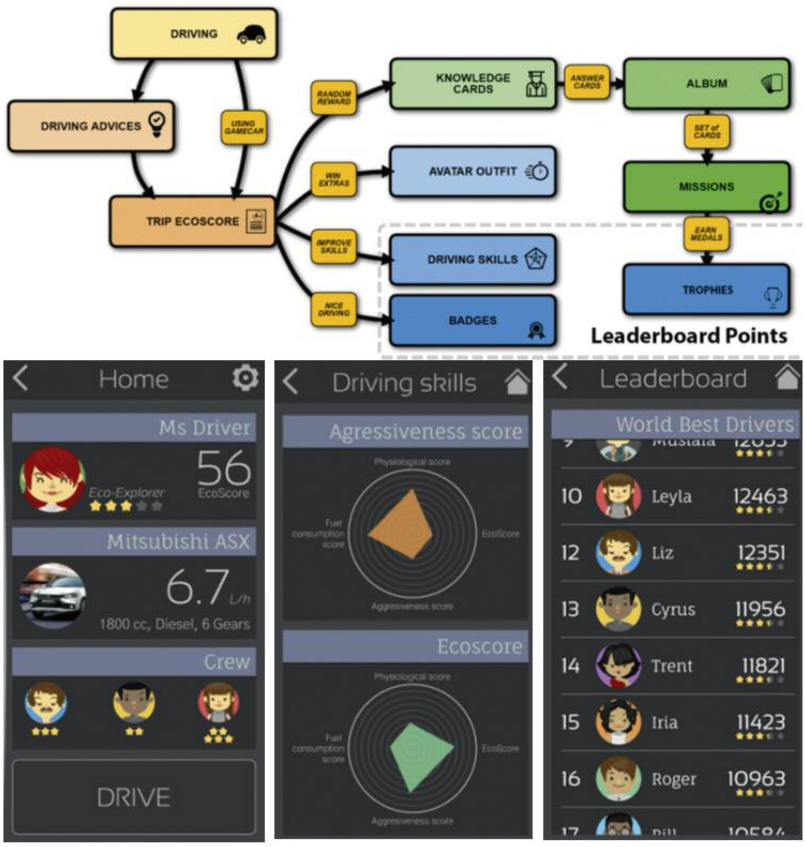

Figure 2: GamECAR gamification design and Integrated Application created by project consortium.

education and health domains (Brainstorm Multimedia), a leading company in delivering advanced hardware and software products in the area of smart devices, building automation and ambient intelligence (SPARK WORKS) and a company with significant expertise on designing, commercializing and implementing technological solutions in domains with advanced automation and safety critical human machine interfaces (KITE Solutions SRL)—see entire project consortium, to implement GamECAR project [L1], with a duration of two years (started on 1st of January, 2017) and funded under Horizon 2020 funding instrument of the European Union. GamECAR project target to deliver s unique personalized system, designed to motivate the adoption of an ecofriendly driving style, without distracting users from safe driving. To achieve its scope, the project has developed and integrated various technologies, including:

- Fuel consumption modeling for Eco-Driving assistance systems;
- A wireless personal network of sensors to continuously monitor physiological, environmental and behavioral parameters;
- Machine learning methods to model and predict driving behaviors;
- Decision support system to provide efficient personalized guidance for the self-management of "eco-driving".

These innovative elements were welcomed by the automotive and the ICT scientific community with extremely positive feedback. This indicates that the project has great potential and the consortium is going in the right direction. In September 2018, the GamECAR system will start to be tested in three different sites in France, UK and Spain, to determine whether it provides the eco-driving benefits to different end users. This is the final step towards a validation and the eventual availability of the GamECAR system to the mass market and other potential end users including professional and non-professional drivers, auto-insurance companies, driving schools, commercial fleet companies, e.t.c.

Link:
[L1] www.gamecar.eu

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CIPSEC: A Commitment for the Future of Critical Infrastructures

by Joaquín Rodríguez and Antonio Álvarez (ATOS)

The goal of the H2020 project CIPSEC is to create a unified security framework that orchestrates state-of-the-art heterogeneous security products to offer high levels of protection in IT (information technology) and OT (operational technology) departments of CI.

Critical infrastructures (CI) are systems and assets whether physical or virtual, so extremely vital to the country that their incapacity or destruction would debilitate the security, economic stability, public health or safety in any nation, even entailing casualties.

CI security features may differ significantly among diverse CIs across different verticals. Each vertical may contain different critical assets, implement different technologies and tools, face specific threats and use different protection methods. With that said, there are shared aspects of security characteristics regarding critical infrastructure protection: High-Availability, Physical Protection, and Cyber Security.

Critical infrastructures rely on technology and communication. The interconnectivity of information technology and industrial control systems has boosted systems performance. However, it has also changed and expanded the likely vulnerabilities, increasing the potential risk to operations.

Field networks have needed to be integrated with IP networks. Thus, sensitive elements like sensors, actuators or delicate processes control systems now are within reach of black-hat hackers. Also, the formerly isolated field networks are still a weak point in terms of security, whose cyber resilience still needs improvement.

Legacy and modern architectures are nowadays interoperating, resulting in more powerful systems that, nevertheless, are prone to present security breaches introduced from the data/communication exchange protocols used to provide such interoperability. Besides, the legacy architectures lack layered defense architecture. This enables hackers to attack these systems.

The CIPSEC Approach

The project CIPSEC ("Enhancing Critical Infrastructure Protection with innovative SECurity framework") is a three-year multi-disciplinary, Innovation Action co-funded by the European Commission belonging to Horizon 2020, the EU Framework Programme for Research and Innovation, starting on May 1st 2016 and ending on April 30st 2019.

CIPSEC proposes a security framework for Critical Infrastructures (CI). This framework makes work together security products provided by different partners, resulting in an integrated powerful approach to protect CIs. The combined features of these solutions will be demonstrated on

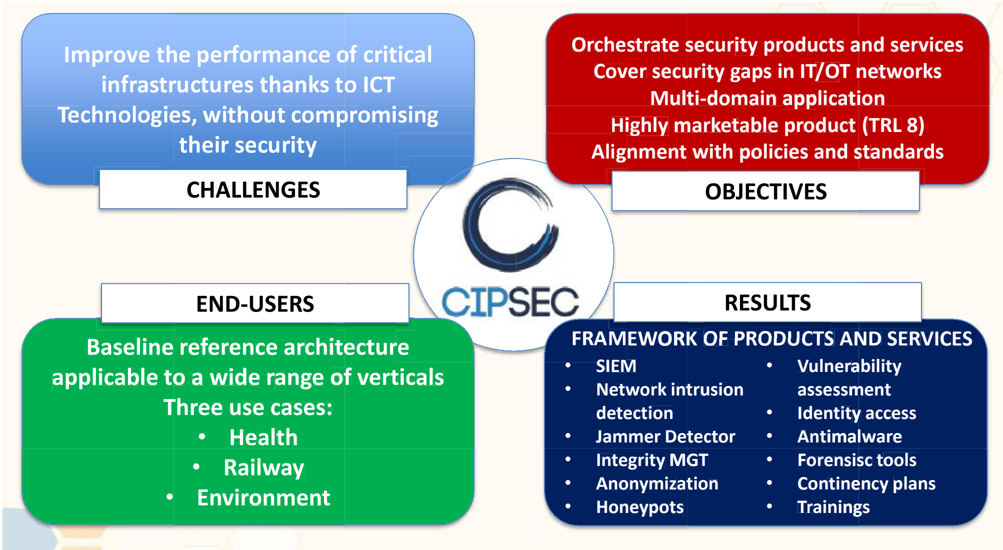

Figure 1: The CIPSEC project in a nutshell.

three different Critical Infrastructures provided by the pilot partners belonging to the Health, Transportation, and Environment CI domains, dealing with major cyber security related issues. CIPSEC major challenges are:
- Research on the dependencies on communication networks and ICT components (including SCADA and IACS systems) of critical infrastructures
- Anomaly detection and avoiding cascading effects.
- Reducing the attack surface of communication networks supporting critical infrastructures.
- Reduced criticality of ICT components installed in critical infrastructures.
- Increased preparedness, reduced response time and coordinated response in case of a cyber-incident affecting communication and information networks.
- Reduced possibilities to misuse ICT as a vehicle to commit cybercrime or cyber-terrorism.

ICT operators (e.g. telecom operators) have experience in securing information networks. This can be applied to new types of networks like smart grids linking communication, energy and transport networks.
Regarding the protection of legacy Industrial and Automation Control Systems (IACS), SMEs are particularly encouraged to provide specific and much focused security solutions adapting current ICT security technology to IACS environments on topics such as:
- Early anomaly detection.
- Patching and updating equipment without disruption of service and tools.
- Improved forensic techniques for supporting criminal law enforcement.
- Anti-malware solutions.
- Proactive Security Systems able to counteract Denial of Service attacks (distributed or not) and other type of attacks aimed to the IACS network disruption.

Keeping these challenges in mind, CIPSEC will create a unified security framework that orchestrates state-of-the-art heterogeneous security products and services to offer high levels of protection in IT and OT departments of CI.

The final framework should be as general as possible but respecting the CIPSEC pilot providers´ security requirements. The project has produced a reference architecture aiming at protecting most of the CI domains.

The design of the reference architecture is domain-agnostic, and is not dependent on any concrete solution. It is inspired in the data life cycle of CI. This process includes the collection, distribution, processing and discovering of data insights. Another principle followed is that the architecture should cover most of the desired key competences in the cyber security disciplines required to succeed on the protection of a wide range of CIs

The core of the architecture is composed by the following subsystems: Anomaly Detection, Integrity Management, Identity Management, Vulnerability Assessment, Forensics Support and Privacy by Design through Data Anonymization, Cryptography Operations, Updating and patching, Dashboards and Users Education based on training courses and cybersecurity awareness.
The CIPSEC consortium is composed of 13 partners including Atos Spain, the University of Patras (Greece), Consorzio per il Sistema Informativo (CSI PIEMONTE) (Italy), the Universitat Politècnica de Catalunya (Spain), the Foundation for Research and Technology Hellas (Greece), the Technische Universitat Darmstadt (Germany), DB Netz AG (Germany), the Hospital Clinic de Barcelona (Spain), COMSEC Ltd (Israel), Bitdefender SRL (Romania), Empelor GmbH (Switzerland), Worldsensing (Spain),and AEGIS IT RESEARCH Ltd (UK).

Link:
[L1] www.cipsec.eu @CIPSECproject

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SpeechXRays: A User Recognition Platform Based on Voice Acoustics Analysis and Audio-Visual Identity Verification

by Emmanouil G. Spanakis (FORTH-ICS)

The vision of the SpeechXRays project [L1] is to provide a user recognition system combining voice biometrics, which are convenient and cost effective, with video, which can help to improve accuracy, and to introduce superior anti-spoofing capabilities. SpeechXRays aims to outperform other state-of-the-art solutions in the areas of security, privacy, usability and cost-effectiveness.

The project takes a new scientific approach to voice biometrics by using human voice physiology, which produces precise acoustic cues that are unique to each individual speaker. The precise vocal tract physiology is directly derived from the feature analysis of the speech spectrogram. We use this information to model the human voice quality characteristics that are used by the human auditory system when identifying a speaker's voice. The project models acoustic cues of voice physiology and detects them in the first pass of a speaker (voice) authentication system in a deterministic discrete time signal processing architecture. Multi-channel biometrics further enhance the system's performance.

The solution combines voice acoustic analysis (rather than models based purely on statistics) with dynamic face recognition (including lip movement and facial analysis). The technology is combined into a unified service capable of running the speaker recognition process: either locally on the device (cancellable biometric template created by binding keys with biometric data and securely stored on the device, for example on the SIM card), or remotely, via a secure cloud connection (cancellable biometric template securely stored on a private cloud, the responsibility of the data subject, and not on the service provider's servers).

The project will test the solution in three real-life use cases requiring various degrees of security: consumer use case (low security), eHealth use case (medium security) and workforce use case (high security). All scenarios will demonstrate an authentication over a secure broadband network giving access to specific services. The technology will be deployed on 2,000 users in three pilots: workforce, consumer and eHealth. The details of the latter are discussed below.

FORTH is responsible for the eHealth use case, deployed in Crete. SpeechXRay's eHealth pilot will test the security, privacy, usability and cost-effectiveness of the security platform. In particular, the scenario will test the context-dependent feature that allows administrators to modify the FAR/FRR trade-off in order to reduce the risk of false reject for low security data (e.g. physical examination) and reduce the risk of false accept for high security data (e.g., MRI/CT scans).

FORTH-ICS, is responsible for running the eHealth use case pilot under the General Data Protection Regulation (GDPR), to allow patient monitoring and medical expert collaboration. The pilot includes the biometric data acquisition and assessment of the provided user identification services, enabling secure access an eHealth collaboration platform for different stakeholders. This pilot (eHealth) will test the security, privacy, usability and cost-effective features of the security platform and the context-dependent features. Once the

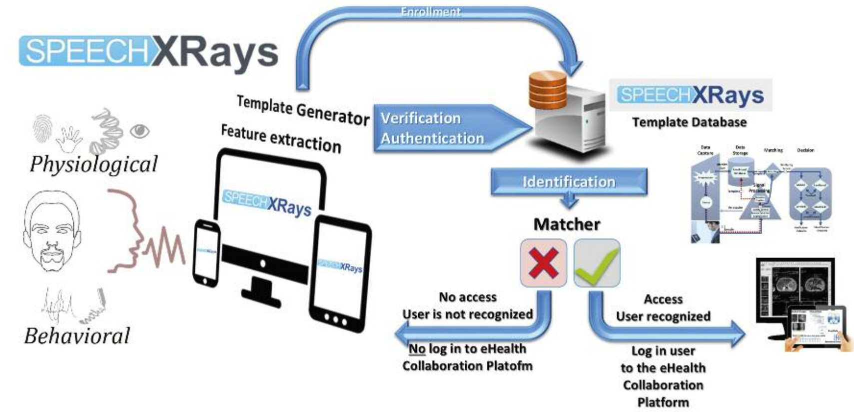

Figure 1: SpeechXRays eHealth pilot study flow diagram for user enrollment and verification/authentication.

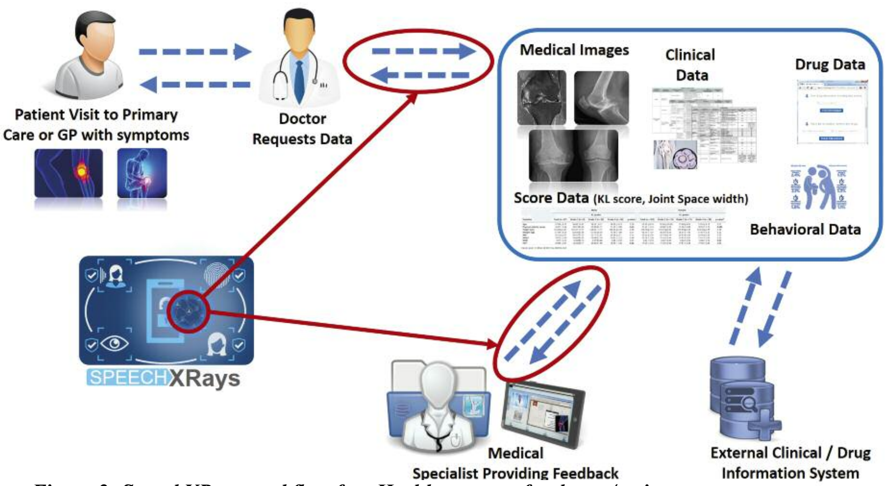

Figure 2: SpeechXRays workflow for eHealth use case for doctor/patient authentication to access medical data.

SpeechXRays security layer has allowed a user to access the platform, the user can access personal health data over 3G/4G or WLAN, from a mobile device (laptop, tablet or smartphone). Patients and doctors will use the remote biometrics solution to access a collaboration platform developed by FORTH to support the prevention and management of a chronic condition (osteoarthritis). Patients will be able to remotely and securely report health data such as activity level, pain, etc. while general practitioners and specialists will be able to access the patient journals for decision-support.

SpeechXRays platform will thus be used to study, how to optimal design a modular biometric platform able to be used in the eHealth domain. Our efforts are focusing on identifying all related benefits of deploying biometric tools that can lead to increased security, increased convenience and increased accountability compared to other authentication methods (PINs, passwords etc.).

Link:
[L1] http://www.speechxrays.eu/

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Universal Housing Technologies

by Emanuele Salerno and Giuseppe Fusco (CNR-ISTI)

Through its unit Integrated Technologies for Quality of Living [L1], CNR-ISTI is a partner of a soon-to-commence project, UNIversalhoUSING. Its purpose is to establish a set of design guidelines for near-zero-emission buildings strictly integrated with their technological facilities, to ensure full compliance with both the existing norms and to meet the needs of inhabitants of different demographics, such as single people, young couples, families with children, and elderly people. A demonstration building will be designed and built on the CNR premises in Pisa, Italy.

The traditional building design approach considered architecture and facilities as two separate entities to be designed independently of one another, and the legislative requirements related mainly to safety and security. More recently, the European norms have been focused on energy efficiency and cost-optimality, thus evolving towards the concept of near-zero-emission buildings (NZEB). By 2019, all new public buildings in Europe should be NZEB and, by 31st December 2020, all new buildings in Europe should be NZEB. With this new focus, the design requirements can no longer treat architecture and facilities as separate concerns: they must derive from the expected functionality of the building-facilities system intended as an integrated object, and must also take into account the needs of the possible types of inhabitants. Reaching this goal requires new methodologies of integrated design where the building, its technological facilities and services, and the expected end users are included in the design constraints.

The UNIversalhoUSING consortium is led by CLC, a building company based in the Pisa area, and includes CNR-ISTI as a scientific-technological partner, LuMar Impianti and Thermocasa, two SMEs active in automation, electrical and heating facilities, and Vivere il Legno, an SME specialising in timber constructions. The project will address and experiment with some building design methodologies exploiting a set of guidelines ensuring costs that are compatible with the current building market, safety, wellbeing, exploitability, manageability, integrability and environmental protection.

A demonstration building will be designed following these methodologies and realised in the CNR research campus in Pisa. The characterising features of this building include systems for comfort and building management, such as sensors and actuators for monitoring and control of air quality and energy consumption, and systems for real-time analysis and post-processing of data to monitor the functionality of the building as a whole, as well as the space occupancy and the interactions among the different rooms. This will enable the managers to plan maintenance interventions and will reduce intervention times.

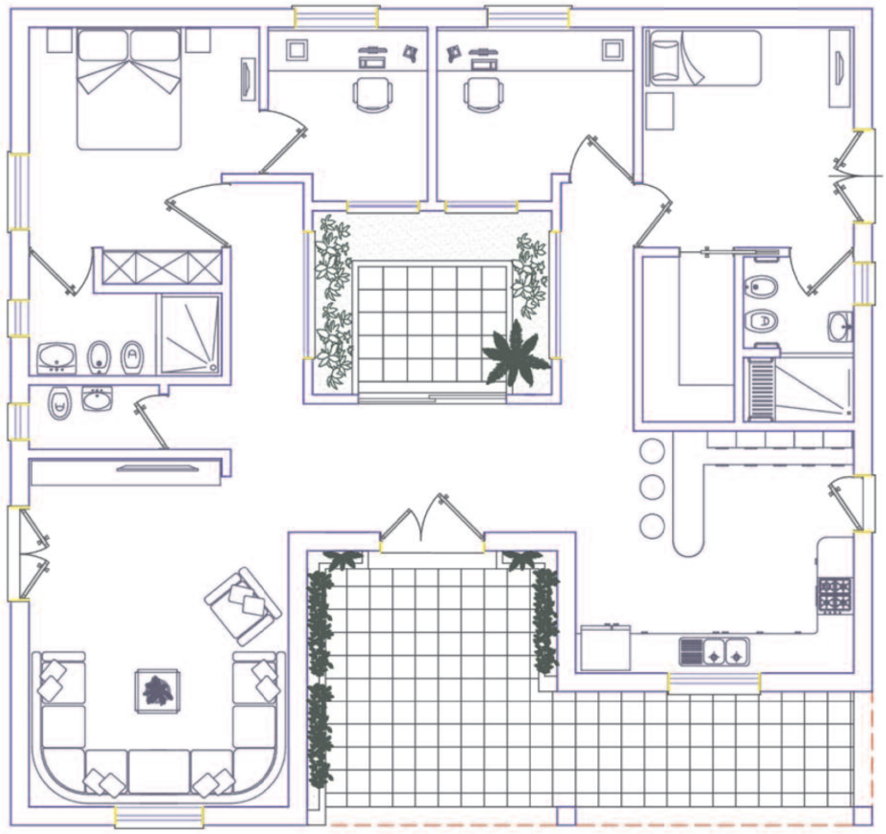

Figure 1: Preliminary layout of the demonstration building.

The main construction material will be timber. Figure 1 shows a preliminary architectural layout of the demonstration building. The building will be accompanied by a use and maintenance manual to optimise its use and prolong its life by enabling an appropriate maintenance schedule, reduced energy consumption, fewer failures and reduced off duty times. The construction site will be open to interested companies and professionals, both physically, in accordance with security requirements, and by web streaming. Also, an information system will be created, containing all the basic information, continuously updated and complemented with the feedback from the maintenance and repair interventions. A full and up-to-date information on all the parts and functionalities of the building will thus be made available for monitoring and maintenance planning, which will also be accessible remotely. The project will last 18 months. At completion, the demonstration building will be used to experiment with new building and technological solutions and train designers and technicians on the new concepts developed.

Figure 2: The "Lucy" technological demonstrator.

ISTI's Integrated Technologies for Quality of Living unit (TQV) is managed by the institute's Signal and Images Laboratory, and is entirely dedicated to the transfer of practical ICT technologies, especially for home and building automation and assistive technologies for disabled and elderly people. Identifying the needs of specific categories of users, in collaboration with the relevant category associations is one of the unit's tasks, as well as organising courses, workshops and seminars for local companies and professionals. The unit has been working with public and private partners in several projects of social housing and transfer of ICT research results to technological applications. In recent years, see Figure 2, the unit has realised and managed a mobile demonstrator of home automation technologies for people with visual or motor disabilities, funded through the EU EQUAL program.

This project is supported with European funds (POR-FESR 2014-2020) by the Toscana region.

Link:
[L1]: http://tqv.isti.cnr.it/index.php

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EL-SIC: Focus on Better and Safer Online Experiences for Kids

by Evangelia Daskalaki, Katerina Psaroudaki (FORTH) and Paraskevi Fragopoulou (FORTH)

In today's digital world, digital literacy and the ability to think one step ahead when utilising the net is vital. The Digital Agenda for Europe [1] aims to provide and promote digital literacy for every European citizen, with a particular focus on children, owing to their particular needs and vulnerabilities on the internet.

The INSAFE [L1] / INHOPE [L2] are the Pan-European organisations that set out the European strategy for a safe and quality internet. The members of the network work closely together to adopt best-practices for online safety at a European level and interact with all stakeholders to bridge the digital divide between home and school, and between generations.

The 34 Safer Internet Centres (SIC), 48 hotlines and 32 helplines operating under the supervision of INSAFE / INHOPE to monitor, co-operate and address emerging trends, while endeavoring to enhance the image of the web as a learning space. SICs make efforts to raise awareness and through close cooperation between partners, law enforcement and other actors, work systematically to eliminate digital illiteracy. They address policy-makers, law enforcement agencies and the internet industry to create a framework that will ensure a better and safer internet and through the organisation of events and campaigns, in an effort to awake and mobilise those involved in every corner of the world. The Greek Safer Internet Centre (EL-SIC) of the Foundation for Research and Technology Hellas (FORTH) is the official Greek representative of INSAFE / INHOPE network.

The Greek Safer Internet Centre at a glance

The EL-SIC in its current form was launched in July 2016 under the auspices of the FORTH, in particular the Institute of Computer Science.

It provides information, assistance and support to young and adult internet users by developing three distinct pillars:

1. The SaferInternet4Kids.gr [L3] portal provides information, including downloadable resources, about the safe use of the internet and social networks. The portal is intended for both parents and educators as well as teenagers and children, and includes appropriate multimedia material. Educational material has already been created and supplemented over time for people with special needs.
2. Through the Help-line [L4], qualified psychologists provide support and advice on issues related to excessive online engagement, online intimidation, exposure to inappropriate content, and other concerns about using the internet, mobile phone and online games.
3. And the Hotline SafeLine [L5] receives reports about child sexual abuse material and illegal online activities [4] and works with both the Greek Police and EUROPOL through European Agency INHOPE.

One of the many achievements of the EL-SIC of FORTH this year was the online research [2] about the use of internet in Greece, based on a sample of 1,100 users. The results of the

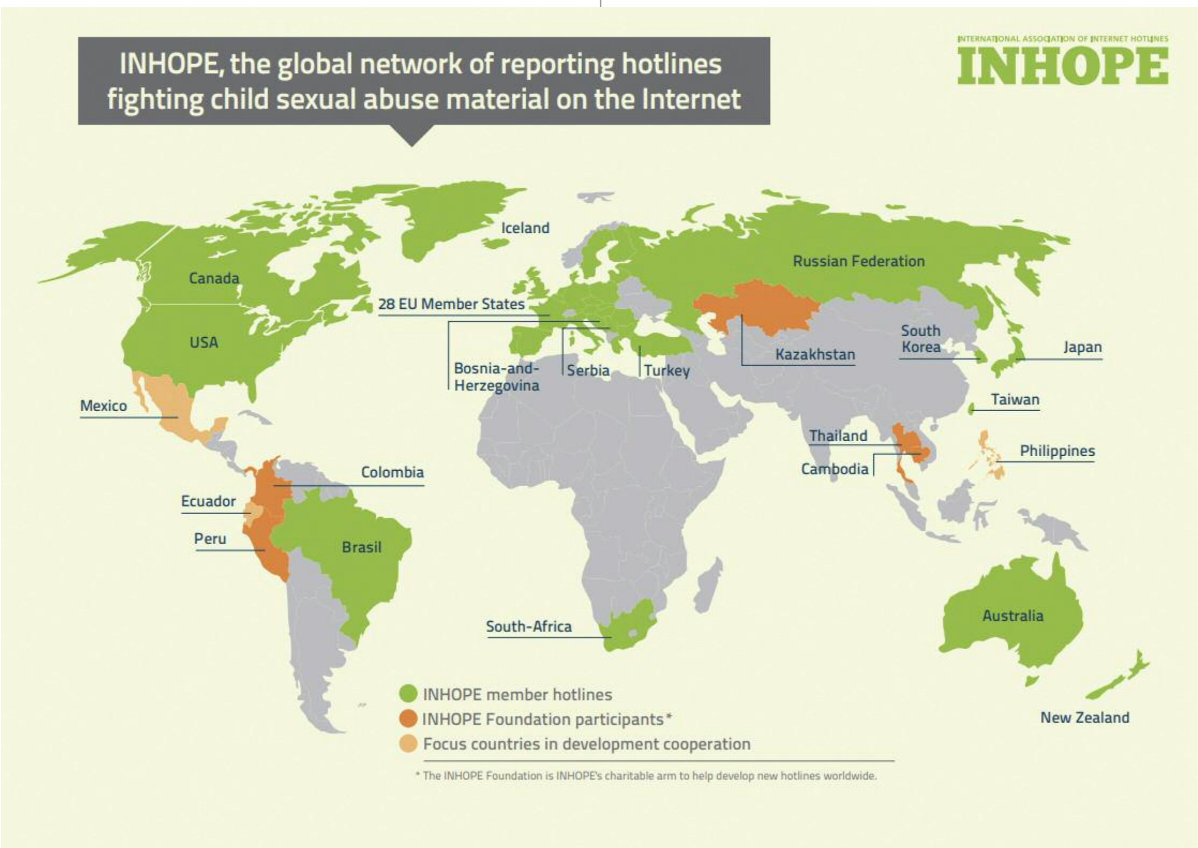

Figure 1: Map of INHOPE member countries.

research confirmed that Greek children use social networks from a very young, ineligible age. It is interesting to note that parents of a higher level of education consider that their child's behaviour is influenced by their social media use and that in times of anxiety their use of social media increases. It has also revealed that social networks can lead to dependency behaviours. The survey further found that 79 % of parents saying their children do not turn to them for help if a problem occurs on the internet. What's more, 16 % of parents admit that they do not know if their child protects its personal data online and 7 % of parents do not know if their child has ever been a victim of cyberbullying.

The third pillar of EL-SIC for illegal online content, namely SafeLine, has received 34,590 complaints during its course

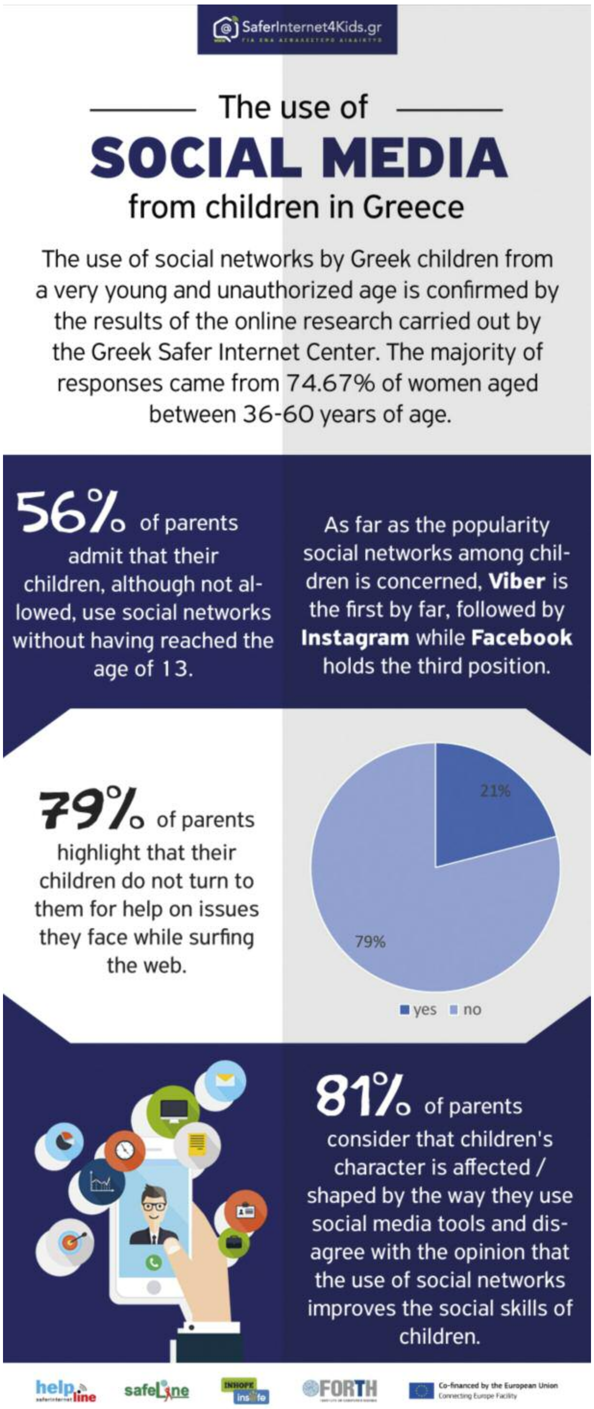

Figure 2: Online research findings.

[3], averaging 4,000 complaints annually over the last five years. Of these, 13,000 were judged by legal practitioners to have a criminal background and were promoted either to the competent Greek authorities (Cyber-Crime Unit) or Europol. Most of the reports received by the line relate to personal data and communication violations (39 %). Next are the crimes of child abuse (21 %), which is the main focus of INHOPE's hotlines and online financial fraud (21 %). In the fourth place are the incidents of hate speech and intimidation (14 %), followed by incidents of violence and threats on the internet.

Links:
[L1] https://www.betterinternetforkids.eu
[L2] http://www.inhope.org
[L3] https://saferinternet4kids.gr
[L4] http://help-line.gr
[L5] http://www.safeline.gr

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- Excellent networking possibilities with more than 10,000 research colleagues across Europe. ERCIM's mobility activities, such as the fellowship programme, leverage scientific cooperation and excellence;
- Professional development of staff including international recognition;
- Publicity through the ERCIM website and ERCIM News, the widely read quarterly magazine.

How to Become a Member

- Prospective members must be outstanding research institutions (including universities) within their country;
- Applicants should address a request to the ERCIM Office. The application should inlcude:
  - Name and address of the institution;
  - Short description of the institution's activities;
  - Staff (full time equivalent) relevant to ERCIM's fields of activity;
  - Number of European projects in which the institution is currently involved;
  - Name of the representative and a deputy.
- Membership applications will be reviewed by an internal board and may include an on-site visit;
- The decision on admission of new members is made by the General Assembly of the Association, in accordance with the procedure defined in the Bylaws (http://kwz.me/U7), and notified in writing by the Secretary to the applicant;
- Admission becomes effective upon payment of the appropriate membership fee in each year of membership;
- Membership is renewable as long as the criteria for excellence in research and an active participation in the ERCIM community, cooperating for excellence, are met.

Please contact the ERCIM Office: contact@ercim.eu

Monique Laurent opened World Women in Mathematics Event in Rio

Source: ICM2018

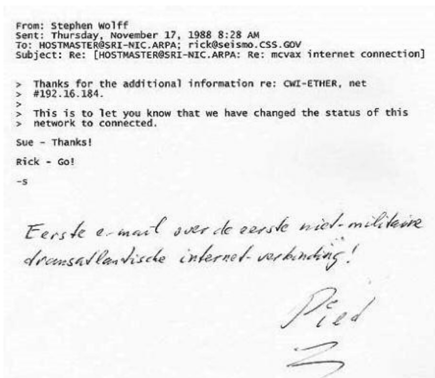
CWI mathematician and computer scientist Monique Laurent opened the World Women in Mathematics event (WM)² in Rio de Janeiro on 31 July with the keynote lecture 'Convergence analysis of approximation hierarchies for polynomial optimization'. The daylong satellite event (WM)² united women mathematicians from all over the world and preceded the International Congress of Mathematicians, which took place from 1-9 August 2018.

Celina Herrera (Federal University of Rio de Janeiro) pointed out that research in this area of computer science is very strong in Latin America, saying it's "inspiring" to have Monique Laurent here in Rio. Monique Laurent highlighted the importance of young female mathematicians having a professional network when starting their careers. "The idea of having a network is very important. It's very touching to be part of this community. It brings me great joy to be here, as part of this big family."

Monique Laurent is a member of the CWI management team since 2016, having led the Networks and Optimization research group at CWI from 2005 – 2016. She is also part-time full professor at the Department of Econometrics and Operations Research at Tilburg University since 2009. She was an invited lecturer at the 2014 International Congress of Mathematicians in Seoul, South Korea.

CWI Celebrates 30 Years of Open Internet in Europe

On 17 November 2018 it was thirty years ago that the Netherlands was the first country in Europe to be connected to the public Internet. System administrator Piet Beertema from CWI (Centrum Wiskunde & Informatica in Amsterdam) then received the confirmation that CWI, as the first organization outside the USA, officially gained access to NSFnet, an academic computer network that later evolved into the global Internet. CWI celebrated this festive anniversary with the publication of a mini-documentary and the unveiling of a timeline with highlights in the building where the Internet in Europe started thirty years ago.



From: Stephen Wolff
Sent: Thursday, November 17, 1988 8:28 AM
To: HOSTMASTER@SRI-NIC.ARPA; rick@seismo.CSS.GOV
Subject: Re: [HOSTMASTER@SRI-NIC.ARPA: Re: mcvax internet connection]

> Thanks for the additional information re: CWI-ETHER, net
> #192.16.184.
>
> This is to let you know that we have changed the status of this
> network to connected.

Sue - Thanks!

Rick - Go!

-S

Eerste e-mail over de eerste niet-militaire transatlantische internet-verbinding!

Piet

The confirmation of the first open transatlantic Internet connection between CWI and the United States . Source: Piet Beertema.

In 1988, after years of preparation (CWI was already the central node in the European 'EUnet' network), Beertema and his colleagues succeeded in gaining access to the—then American—internet, thanks to their good contacts in the network world. Other European research institutions were connected shortly after CWI. Commercial companies followed later, and private individuals had to wait until 1993. CWI became an important network hub between Europe and the United States. Nowadays, still a considerable part of the European internet traffic runs through the Amsterdam Science Park, where CWI is located.

SCHLOSS DAGSTUHL
Leibniz-Zentrum für Informatik

Call for Proposals

Dagstuhl Seminars and Perspectives Workshops

Schloss Dagstuhl – Leibniz-Zentrum für Informatik is accepting proposals for scientific seminars/workshops in all areas of computer science, in particular also in connection with other fields.

If accepted the event will be hosted in the seclusion of Dagstuhl's well known, own, dedicated facilities in Wadern on the western fringe of Germany. Moreover, the Dagstuhl office will assume most of the organisational/administrative work, and the Dagstuhl scientific staff will support the organizers in preparing, running, and documenting the event. Thanks to subsidies the costs are very low for participants.

Dagstuhl events are typically proposed by a group of three to four outstanding researchers of different affiliations. This organizer team should represent a range of research communities and reflect Dagstuhl's international orientation. More information, in particular, details about event form and setup as well as the proposal form and the proposing process can be found on

http://www.dagstuhl.de/dsproposal

Schloss Dagstuhl – Leibniz-Zentrum für Informatik is funded by the German federal and state government. It pursues a mission of furthering world class research in computer science by facilitating communication and interaction between researchers.

Important Dates

- Proposal submission: October 15 to November 1, 2018
- Notification: February 2019
- Seminar dates: Between August 2019 and July 2020.

ERCIM – the European Research Consortium for Informatics and Mathematics is an organisation dedicated to the advancement of European research and development in information technology and applied mathematics. Its member institutions aim to foster collaborative work within the European research community and to increase co-operation with European industry.

ERCIM is the European Host of the World Wide Web Consortium.

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