A Vision on Collaborative Computation of Things for Personalized Analyses

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Abstract—This is a visionary introduction of a technical opportunity to engineer and maintain a more aware daily life based on continuously updated scientific results and research in such fields as Cyber Physical Systems, Internet of Things, and Modeling and Simulation for engineered systems. A conceptual framework called Computation of Things is proposed, a technical engine as an online platform is being collaboratively developed, and first results on domain convergence in both emerging technologies and applications are discussed.

Keywords: modeling and simulation, multi-paradigms, engineering systems, quality assurance, software engineering, social science, social change

I. VISION OBJECTIVES INTRODUCTION

Awareness about human reactions to different life situations is often claimed by psychologists as a means to make proper decisions [11]. Thus, research into appropriate sets of solutions to raise this awareness is paramount. The convergence of recent technological advances and concepts, such as cloud and high performance computing, information access, data sharing, and Internet of Things (IoT) enable the design of a framework that allows for effective human-computer interaction. This paper explores how these advances can be employed in combination with Modeling and Simulation (M&S) techniques based on a framework called Computation of Things (CoTh).

In the framework, computational modeling, simulation, and analysis are the main drivers of paradigm shifts. As a consequence, the underlying computational science becomes pivotal in order to realize the vision. Further, advances in computational studies are proposed to be combined with the science related to human wellbeing. As such, Human-in-the-Loop (HLoop) simulation is considered of paramount importance. The proposed vision, called Computation of Things (CoTh) is a scientifically-founded human guidance system embedded in a trusted social network. It serves to empower a human being to achieve self-expressive positive impact. It makes us think of things that really matter to us such as human daily-life problems and grand challenges instead of being only a consumer. Clearly, CoTh is a response to the Internet of Things [36] where all objects around us are envisioned to include a traceable chip and form a near invisible global network of radio frequency identification tags deployed on them. Similarly, CoTh builds up on the concept of the Web of Things [34] defined as an alternative vision of how the Web of tomorrow could be expressed. Web of Things is then an extension towards a virtual mechanism emulating the sensing capabilities located worldwide. It is a type of connection between the physical world and cyberspace.

In addition, the notion of cyber-physical systems (CPS) [17] is relevant for CoTh. CPS is frequently characterized as a smart system that includes digital and cyber technologies, software, and physical components. It is intelligently interacting with other systems across information and physical interfaces. It is expressing an emerging behavior and so, creates multiple live functionalities during its deployment. CPS is sensing the external world to immediately react on the state of the surrounding and is embedded in an IoT network.

In light of those technological developments, the main investigation problem this paper and the CoTh vision is concerned with relates to providing a better quality of life for an individual by means of computational modeling, simulation, and analysis in an as efficient manner as possible. In other words, the main issue is to explore and predict how the level of awareness of any aspect (e.g., genetics, lifestyle, educational level, geolocation, regional pollution level, etc.) of an individual’s life is going to contribute to better, more fulfilling, and sustainable decisions for this individual (cf. [11]). Awareness is defined as understanding of the current situation about an individual’s life (i.e., here and now) and possible future consequences [35] depending on the choices one can make.

Decomposing the analysis, the following general questions arise:

− How can a layman human leverage the technology so as to perform more intelligently than ever before, especially in the context of living a more fulfilling life?
− What is the role of predicting different life scenarios and how does the prediction contribute to decision making?
− What are the implications for a human? Does the socio-technological merge form a ‘Superorganism’ [1] or is it an illusion?
− How can the life of a person be improved, under which conditions, to what extent? What are the pros and cons?
Given the appropriate tools, can we engineer a better, more aware, and more empowered quality of life by ourselves (e.g., everybody on their own accord)? Before making an attempt to answer those philosophical-type questions, the technological issues arise:

- In the context of modeling the behavior of a human and the related quality of life the following challenges evolve. What are the types of models involved? What elements do the models include? What concepts on modeling, simulation, and computation from the engineering world should be transferred to the emerging field of engineering sustainable life?
- How to technically realize the vision of such a personalized computational framework? In particular, how to include hybrid dynamic behavior models into the framework and reliably analyze them?
- How to integrate the available data (including big data [9]) and models in the overall framework so that they will be useful to an average technically literate person?

The proposed vision demonstrates the potential to dramatically improve human awareness because of the scientific inclinations involved in the process of CoTh creation and application. Then, if the results are merged with the reliable analysis of a self, surrounding, and the social network of a person, it increases the confident performance of a human (e.g., at work, in personal life) and hints at the ability to revolutionize social environments by compassionate problem or conflict resolution [11]. The study enables more efficient and fulfilling life scenarios. Moreover, CoTh relates the needs of an individual to sustainable development\(^1\) requirements so that human actions can be focused towards achieving the personal goals in harmony with the surrounding (e.g., with the Earth environment).

The main technological challenge comprises the integration of all the aspects and assuring a proper reliability level of the prediction methods. Modeling and Simulation (M&S) concepts are borrowed from the engineering disciplines to better understand and engineer human life interactions. An initial architectural design for CoTh integrates (1) participatory sensing and remote sensing platforms [15][28], (2) a computational analysis engine, and (3) visually-spectacular interfaces that support decision making [37] as provided in Figure 1. The focus of this paper is limited to (2) and some parts of (3), though, and is based on the already existing data for (1). The overall architecture borrows from multiple, heterogeneous designs to provide an efficient, generic CoTh platform. It includes studies of selected existing components for data integration [4][14] and the insights into the computation engine itself.

One of the aspects to realize this vision is to create a crowd-sourced M&S platform facilitated by the community belonging to the simulation social business network that is currently under development at SIMULATEDWAY [30]. It is connecting the passionate engineering communities with human life problems to foster collaborative innovation [10] (cf. InnoCentive [12], SPRUCE [31]) in applying simulation as a tool for understanding ourselves and directing our mind to make a positive impact. The online service includes an optional encryption option to deal with the privacy problems and offers IP-protective solutions. Key features of the CoTh-engine-based online service from the usability viewpoint include: (1) self-organizing communities of interest, (2) dynamically evolving challenge problems with accompanying artifacts, and (3) built-in experimentation facilities to collaboratively reproduce the problems and evaluate solution benchmarks.

Figure 1: Computation of Things and its broad CPS-related context.

Figure 2 illustrates the technical aspects for the CoTh engine. It consists of two logical components: Technology Management (TM) and Collaborative Knowledge Management (CKM). TM includes an online platform design where such components as domain-specific views, M&S cloud-based tools, collaborative user interface for technical execution of the simulations, and guidelines for the users are available. CKM allows the community to create problem and solution spaces that then drive M&S collaboration using the tools available in TM. Here, analyses, big data incorporation, and semantics transformations take place. The execution-based computational semantics framework described in Section III is incrementally advancing here as well.

II. COMPUTATION OF THINGS AND THE STATE OF THE ART

In the proceedings, examples of CoTh usage and related work on the technology are introduced.

A. Vision

Novel approaches to leveraging the ever increasing amount of data about humans and surrounding physical and biological phenomena together with modern prediction algorithms allow for transformative thinking about a new kind of computational

\(^1\) Sustainable development is defined as the development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" [35].

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Image 2: Collaboratively created CoTh engine.
CoTh enhances the corresponding transformation by delivering a set of tools to take a conscious, scientifically-founded action as a response to computational thinking. It clearly requires a deep technological understanding of the current state of the art in many disciplines (e.g., social computation, human computing, knowledge-based computation, human-based computation, human-centered computing, citizen science, human-computer interaction, nature-inspired computation, etc.) and establishes expertise for every human in a broad range of application areas. As a result, each person is becoming a realistic and reasonable source and recipient of knowledge (and wisdom) on forecasting their own walk-of-life alternatives [7][8].

The intent of CoTh is to provide a methodology and toolset to predict effects of diverse decisions on different levels. For example, given that a person chooses a particular means of transportation and route to work for, say a year, CoTh can be utilized to provide a set of predictions on how this affects carbon dioxide emissions. As a further example, a person's DNA may be correlated with nutritional habits in a simulation that allows for estimation of health effects, including various possible detrimental effects. From here, the approach can be scaled up to families, communities, and nations. Clearly, further criteria can be added to the examples. Depending on the considered group these criteria may include further risk exposures, such as likelihood of terrorist attacks in case of organizing the defense logistics, people's migration paths in case of severe weather conditions, effects of a resource scarcity crisis, or likelihood of violence, to name a few. The applications of CoTh are manifold. Other examples include selection of the safest and healthiest way for sending your children to school, choosing the best place to live in accordance with your preferences, but also specific personal conditions or diseases, up to individual evacuation plans during natural disasters [33].

Thus, when designing the CoTh engine, the technical challenges include domain- and cross-domain interactions, an equally distributed access to data (e.g., big data), knowledge, services, and predictions, assuring a proper analysis of data and behavioral simulation models [9][22]. The forecasting of scenarios should be possible by analysis in time and space based on patterns to find similar situations and comprehensive sets of possible answers. Real-time data from sensors (e.g., those belonging to a person's social network) should be acquired to establish a current situational awareness [1]. Further, alert information about any sudden changes or anomalies that could significantly impact the prediction output should be supported (e.g., civilian guidance in environmental crisis [4][5]). CoTh is based on the principle 'to share is to gain' and it requires increasing personalization for a single user. Thus, its implication shall be a transparency of things [14][32], where ideally a personalized degree of privacy is maintained while making selected information available.

B. Technological Realization of the Vision

Considering CoTh it is imperative to study software development practices and Model-Based Design techniques to inherently enforce the laws of physics. Computational modeling is an important element in the design of engineered systems. For example, computational models, because of their predictive power, are an essential part in designing efficient control strategies [24], decision-making, and early-warning systems [3][4]. Given that a good model is one that helps solve the particular task at hand, a physical system may be represented by many different models. Each of these models is then most efficient for solving the particular issue under study, and, therefore, ideally only those phenomena observed in the system that are considered of importance are embodied by the model. All other phenomena are best abstracted away [23]. On the other hand, the complexity of desired functionality and the difficulty of software design have proven to be a magnificent challenge for the design of reliable systems. This has brought about a need to raise the level of abstraction and to remove any 'accidental complexity' from the separate design activities. Model-Based Design has demonstrated its success in tackling these issues when building complex systems by supporting requirements traceability, executable specifications, automatic code generation, and facilitating continuous test and verification [24].

Finally, the CoTh vision includes an abundant supply of computational capabilities for individual scenario prediction and decision-support that would be economically viable for every person on the planet. In this work, the analysis and prediction core (called computational semantics framework in Sections III and IV) is given particular attention. The main obstacle in increasing the forecasting power of computational models in the engineering world nowadays is their still poor understanding and lack of accuracy that ultimately leads to extremely high verification and validation costs. Therefore, based on engineering studies it is proposed in this work to formally define the computational approximation (i.e., error) as a development artifact [24]. This allows refinement of the semantics of a computational model by adding necessary modeling constraints and enforcing relevant domain characteristics of a dynamic system during development.

C. Reality Check

In summary, the shortages in building CoTh recognized in today's convergence of different HLoop-relevant aspects arise mainly from the lack of a common purpose catering to a single individual. If merged and analyzed together current disjoint technology advances expose a potential to provide fitting solutions to some of the issues critical for building situational awareness. Hence, although currently many approaches related to such fields as, for example, early-warning disaster systems [5][33], crisis crowd sourcing [3][4], or digital infrastructure plans exist, there is no common understanding in terms of combining them into one ubiquitous platform. Moreover, there is a lack of in-depth analysis of the cross-cutting concerns. For example, the relation of, say, health problems, geo-location, and social networks is not yet extensively researched, only limited attempts of patterns extraction exist [37]. Then, clearly, there is no relation of any of such issues to a single citizen. Further, there is no full leverage of modern software engineering principles, and consequently little simulation attempts, no forecasting, and no relation to the big-picture vision. There is little work addressing the development of
adaptive systems based on the dynamics of situational change embracing many different perspectives. Further, no fusion of isolated data into a common analysis framework exists, although some attempts have been made, for example, for disaster response [13].

III. METHODS AND DESIGN TO REALIZE THE COLLABORATIVE COMPUTATIONAL SEMANTICS FRAMEWORK

In this section, an initial concept for creating the computational semantics framework is discussed and the concrete methods for its realization are introduced. As highlighted in Section II, Model-Based Design (MBD), including high-level modeling, low-level coding, and sophisticated implementation of the execution technologies, is nowadays extensively applied to create complex engineered system. To the end of the development workflow difficulties, things escalate when the unknown and untraceable computational approximation between the development artifacts is added. The complexity is growing even more when hybrid dynamic systems are considered as now the hybrid of continuous and discrete behavior and must be analyzed and synthesized. This again, divides the development into further separated and frequently isolated parts and hence, increases its already complicated nature and reduces the potential for a unifying flexibility throughout the entire process of a product creation.

Therefore, herewith, an approach to defining a novel computational semantics framework (see Figure 3) based on a clear separation of execution semantics concerns is proposed while the typical issues related to the specific domains of Engineering (e.g., numerical integration methods) and Computer Sciences (e.g., solvers abstract specification, model transformations of the execution algorithms, Model-Based Testing) are still honored and acknowledged as development artifacts as opposed to abstracting from them [23].

![Computational framework for CoTh—global structure view.](image)

As the abstraction level should not negatively affect the execution, in the following, an approach to reasoning about the process for developing an engineered system evolves from the ability to understand the executable design of a system in a novel manner. It embraces current MBD practice and allows for an abstract definition of the system execution logic at the early design phase, in addition to the abstract definition of the system model. An explicit creation of this execution logic artifact takes place at the same stage as the system modeling does. This then enables reasoning about the simulation and obtaining meaningful results at an earlier specification level than before. Also, starting from this early design level, the simulation becomes semantically consistent throughout the entire development process. This is because of leveraging the definition of the computation execution logic that is now available and does not change through the later development stages. In other words, the error introduced by a computational approximation of the execution is accepted as an inherent system artifact as early as in the abstract development stages, but this sort of abstraction does not reduce the value of the simulation analysis.

To contrast this approach with current development practice the reader is encouraged to consider the following. A computational analysis and synthesis of the code base underlying the simulation is nowadays increasingly difficult because of the rapid pace with which the code is growing. Therefore, the opportunity to define the execution logic before the code is created moves the analysis process to the earlier stages and introduces new capabilities for understanding the model and simulation results. It also allows for incorporating a vast number of Computer Science methods to synthesize simulation output, which otherwise would not be possible [26]. Relating to the CoTh engine, a semantics-based collaboration on the execution logics as such is now possible between multiple domain experts. Models of computation can be exchanged, modified, and the underlying algorithms can easier be identified. A discussion on the approximation trade-offs is being open to the simulation community and the technical means to support the simulation experience become available immediately, all in one common technical environment.

A. Stratification of the Computational Semantics Framework

The proposed computational framework is stratified (see Figure 4) and includes such layers as a declarative definition (i.e., what does the simulation execution do), operational semantics (i.e., how is the computation functionality defined), implementation (i.e., how is the computation functionality translated to the available implementation means), the technology (i.e., how is it going to be interpreted by the current technologies), and a mapping to a specific deployment platform (i.e., what platform could be utilized to take on this technology and how will it be realized) [18][27]. Additionally, the system models specification (on the left) links to those strata.

![Computational framework for CoTh—semantics view.](image)

Presenting the framework in a unified form emphasizes the importance and potential of the declarative definition of the simulation (i.e., execution logic). From here, different types of
solvers can be defined applying one common abstract and technology-independent notation that will then enable reasoning about certain types of equations as early as at the beginning of the system specification. Those newly defined solvers (similar to the currently available methods) introduce approximation errors to the computational results, however, these errors are controllable and intentionally defined by accepting the limitation of computational analysis as such. Such a methodology then enables consistently maintaining the clearly specified errors throughout all development phases and by that, avoiding complexities that arise from inconsistent approximations as known from current industrial practice.

In the proposed computational semantics framework, the ‘accidental complexity’ of the code that is normally used for computation implementation is removed by application of a representation of the considered phenomena on a higher level abstraction. Thus, the reliability of predictions is increased by capturing the dynamics of the computation in an abstract notation, such as, for example, causal block diagrams [25]. This declarative, purely functional, and side-effect free approach makes solver dynamics explicit and allows a computational framework for enforcing inherent dynamic systems semantics. As a result, M&S collaboration on the simulation execution logics that has formerly been unavailable for computer scientists is enabled. Also, correctness and consistency of the computations as representations of dynamic systems can be guaranteed by construction at this level. Details on the topic have been presented in previous work [25][38].

B. Illustrative Scenario

To understand some of the technical aspects proposed in this paper, consider the following scenario. In Figure 5 a social network embracing several people is presented. The assumption is that each individual deals with the same ten elements listed as those that are contributing to life quality. On the one hand, one type of model (behavior model type 1) can be obtained from the analysis of the existing datasets on a certain topic, for example, reasoning about the spread of certain phenomena. Such a reasoning is performed, for example, at the Harvard Christakis Lab [2] or MIT Media Lab (cf. Social evolution or Reality mining projects [19]). Here, questions such as how opinions and behaviors spread in face-to-face networks are considered. For example, the spreading of political opinions, influenza, stress and loneliness, and weight changes is measured based on data recorded by automated sensors. The characteristic variations in individual behavior can then be used to accurately predict the resulting human-dependencies network across various contexts.

On the other hand, certain other aspects about an individual person can be projected in a mathematical manner so that numerical models of different human behavior are obtained. Those models can then be simulated in isolation to see what different scenarios are to be expected. This is represented by the behavior model of type 2 in Figure 5. Whereas models of type 1 are increasingly being investigated, models of type 2 are not yet developed at all. Additionally, so called domain-specific models (i.e., models of type 3) enhance the view. An example of such a model is the human DNA where the overall genetics concept is investigated globally rather than at the individual level. Another emerging analysis method of the domain-specific models is crowd sourcing of the behavior of interest and letting the community (e.g., the so called citizen scientist) enhance the model. The service CureTogether [6] is an instance of such a methodology. Here, diet, sport activities, and health tracking are studies in combination by the interested self and the supporting crowd. The goal of the computational semantics framework is to enhance such analyses in a collaborative manner and learn about the simulation semantics using different types of models.

As provided in Figure 5, the analysis of the models occurs during and after the simulation. This indicates that the models must be executable, to begin with. Then, selected simulation methods (e.g., different numerical integration schemes, execution paradigms) affect the analyzability of the cascading effects. This problem is known in other domains, such as, for example, automotive domain, engineering practice [21][23], disaster management [3], or crisis response [13]. Therefore, it should be aimed for a joint effort to deliver a set of solutions when relating to HLoop problems.

IV. Vision Risk Assessment and Future Work

The risk factors related to the presented vision comprise at least two types. Firstly, the challenges resulting from the integration and heterogeneity as well as the futuristic and multidisciplinary views may be too difficult to be solved within the next few years. Thus, the timeline for the complete realization of the vision is not definitive. As a mitigating factor, however, considering the exponential growth and convergence of the underlying technologies, the solutions may emerge quicker than anticipated [16]. Further, privacy and policy issues are very much at the forefront of a very active research and development field. Technological game-changing developments, such as parallel computing, novel computational algorithms, and next-generation computation and prediction capabilities require strong abilities to adopt the CoTh system to emerging architectures and infrastructures, but if this is successfully performed they open the door to rapid progress.

The technological concepts introduced in Section I and Section III have been addressed in a prototypical design and a partial implementation of the technical engine provided by SIMULATEDWAY. These will be described in more detail in a subsequent publication.
CoTh and other systems alike must be implemented to help people find the best paths in their behavior. It is frequently the case that people are not aware of the consequences of their actions. CoTh will change this trend into a decision-awareness mechanism. CoTh is also anticipated as an enabler of more altruistic viewpoints based on the psychological research results that have proven the assumption that the higher the level of fulfillment of an individual, the better efficiency, effectiveness, and sustainability of the surrounding systems and group performance (cf. [1][2]).

ACKNOWLEDGMENT

The author would like to sincerely thank her continuous collaborator, Dr. Pieter Mosterman for technical insights and Volkswagen Foundation reviewers for useful comments.

REFERENCES


