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Reasoning Strategies in Smart Cyber-Physical Systems

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Abstract

Cyber-physical systems are integrations of computerized physical things in the environment that are merged by communications, and computations using embedded systems and networks. To make the components of the systems act intelligently, according to users' needs, and understand and predict behavior of the cyber-physical systems, the cyber-physical systems need reasoning to link the outcome of the different components to be able to make use of the devices in the surrounding environment. The reasoning includes collecting sensor data, finding key concepts in the data and drawing conclusions that cyber-physical systems can use to control the components surrounding the users. However, there is a range of different components in a system where each has particular communication input-output and its own set tasks, which provides particular challenges associated with controlling or predicting the behavior of such systems, which require a kind of analytic tools. This paper presents reasoning strategies for smart cyber-physical systems that can extract and combine data, information, and knowledge to provide an intelligent behavior from users point of view. The reasoning strategies use users' needs as a starting point and provide an environment that gives personalized support.

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Keywords: Cyber-Physical Systems; Internet of Things, Reasoning; Decision-making; Intelligent systems

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1. Introduction

Cyber-physical systems, CPS, are often referred to systems that feature a tight combination and coordination of computational and physical components [1], which use computations and communications that are deeply embedded in and interacting with physical processes. The CPSs are commonly more than embedded systems, with standalone elements, since they typically are designed network of interacting computerized physical things in the environment, which are integrated by communications, and computations with and between physical processes [2]. The communication is incoming sensor data from and to physical components, such as Internet-of-things, in an environment, where human beings is an integral component (which nowadays is role player of the so-called mobile cyber-physical systems). Hence, beside the notion of being robotics and sensor networks with intelligent mechanisms, CPS will become intelligent mechanisms, which for example will increase functionality and usability in areas such as augmentation of human capabilities for healthcare monitoring and delivery [3].

The last five-ten years, a tremendous progress has been made in advancing CPS technology but there is still not any mature science that supports system engineering of high-confidence CPS [4]. New components and relationships in the cyber-physical network require definitions and redefinitions of forms and functions to handle the challenges of large, spatially, temporally, hierarchically and heterogeneously distributed CPSs. Moreover, the thrusts of CPS technologies in Internet of Things (IoT) underpin the integrations of a myriad of physical components and processes that are more or less developed by external actors, which behavior affects overall system and requires coordination of the IoTs. Hence, there is a range of different components in a system where each has particular communication input-output and its own set tasks, which provide particular challenges associated with controlling or predicting the behavior of such systems.

To be able to make use of the components in the surrounding environment, including the users, intelligent reasoning is applied. The reasoning is used for linking the outcome of the different sometimes interconnected components, accordingly to users' needs, and, thereby, making the components of the systems act intelligently moving to a smart everywhere society.

This paper presents reasoning strategies for cyber-physical systems to extract and combine data, and information to provide an intelligent behavior from users point of views. The reasoning strategies builds on users' needs as a starting point and provides an environment that gives personalized support. From the sensor data of the users, the system can find key concepts in the data, and collect data according to the concepts and then reasoning draws conclusions that cyber-physical systems can use to support the users by providing support via the components surrounding the users.

2. Cyber-Physical Systems

Cyber-physical system has been presented with many different definitions. The term Cyber-physical system means different things for different people [5]. One of the earlier definitions and most known and accepted is "Cyber-physical systems are integrations of computations and physical processes" where embedded computers, and networks monitor and control the physical processes [2]. The physical processes are "sustained phenomena and clearly noticeable gradual change through series of states" but it does not have to be carried out by physical entities and, form the beginning, the devices principle mission was not computation. Neither, does it have to be a continuous action or series of changes, which alters the material form of matter.

After years of using the term, it is more widely defined. Nowadays, cyber-physical systems also refer to integrations of computation, networking, and physical processes where embedded computers and networks monitor and control the physical processes using feedback loops [6]. Then, the cyber-physical systems are feedback systems that are networked and/or distributed, adaptive and predictive, intelligent and real time, but also possibly including humans in the loop, which integrates dynamics of the physical processes. The integration is then software and networking, which includes techniques for abstractions, modeling, designing, implementations and analyses.

Although the cyber-physical systems were not defined and implemented only for stationary devices in mind, a more specific term has been defined: Mobile Cyber-Physical System. Mobile CPSs are systems that are composed of "physical and computation components that are mobile and can communicate over a network". In these systems, the physical system has an inherent mobility, for example robots or electronic devices carried around by humans or animals like smartphones. These devices commonly communicate with local resources to carry out tasks but when other resources are needed, network is used to connect to these devices that may or may not be mobile.

The essence of the cyber-physical systems is that the systems are Information and Communication Technology (ICT) systems that are confluences of embedded systems and networks [5], which are integrated in the environment. The smart cyber-physical systems are integrations of innovative applications and services, which include exploited Internet of Things, smart devices, and small wearables to provide intelligent and autonomous and/or automatic systems and become "smart everywhere society". Although "smart everywhere" starts to happen, technology and real-time platforms are missing and there are knowledge gaps [5]. For communication, the cyber-physical systems require an improved infrastructure with sensor-based communication-enabled automatic systems including computational devices and physical processes, i.e., devices for measuring things as well as intelligent decision-making and negotiations [7].

New technologies will not be successful without the participation and the acceptance of human beings who will use the products and services [5]. Nonetheless, the interactions cannot be made with humans in the loop pressing buttons. Instead, the systems need to be autonomous and/or automatic, where the term autonomous often refers to unsupervised action of, e.g., robots, and the term automatic systems characterize the expected performances of the systems, such as automation of decision-making. This will affect the manner in which humans will interact with the systems and, therefore, a kind of "Human Centric Cyber-Physical Systems" is required [5] where socio-space is considered in the cyber-space and physical space. This imposes a need for cyber-physical systems with higher reliability, dependability, more complexity and connectivity, as well as mixed criticality where systems containing computer hardware and software can execute several applications of different assurance levels that can execute in real-time.

Since software is a key factor in the infrastructures with integrated platforms, cyber-physical systems need to handle devices together with information about, e.g., time, positions, measurements, and space. The devices represent the myriad types of data and applications, which are in contexts within different physical domains, and, hence, knowledge engineering plays an important role [8] as well as reasoning strategy to handle the outcome of the devices. Conclusively, intelligent-based systems using reasoning should be incorporated in cyber-physical systems to improve the design and functionality of these systems. These smart cyber-physical systems should offer adaptive, predictive and robust behaviours and capabilities from the users' point of view and provide self-healing and augment human capabilities in decision-making.

3. Cyber-physical system and communication between the devices

Since, cyber-physical systems integrate the physical world, embedded systems and the Internet, it has a particular set of devices with connections between the different devices. The devices are things equipped with software and electronics using sensors and actuators and Internet of things, i.e., scenarios where things are equipped with unique identifiers with the ability to transfer data over network without interference of human beings. It can be heart monitor implant, built-in sensors, or computers, and any other things that can communicate with its environment and Internet. Although, some claims that cyber-physical systems are creating an Internet-of-things, we deliberately differ between the devices with the argument that not all devices need to be connected to networks. Hence, we do not want to use the terms cyber-physical systems and Internet-of-things as interchangeable terms.

There are several different kinds of data transported to and from different devices, e.g., sensor signals, single and complex data, information pieces to webpages, and documents. Sensor data of the users wearable devices can be sent to surrounding environment. From the signals, the system in the user device can connect to different kinds of devices, such as databases, web sites, external physical things and IoT devices. Each of these will give some output, either as data, pages, locations, 1 or 0 and so on. The user device system must find key concepts in the data, and collect data, from external devices. Using the concepts, the reasoning draws conclusions that cyber-physical systems can use to support the users via the components surrounding the users. From the collected data, the system will use reasoning to provide decisions to the user.

The data is passed to and from different devices in the CPS, in the format that is required by the devices, by using different communication means, each which the user device system must handle. This can be handled by one single protocol that support each communication means [9].

A figure showing the different devices that are, at least, expected to be involved in a common everyday situation are presented in Figure 1. The situation is built on a real case, with personlised health care is in focus.

Fig 1. A real-life situation case for device usage in Cyber-Physical System.

In the figure, Figure 1, several measuring devices are included, in the middle and on the both sides. The middle picture is the user device that is communicating with the devices in the local environment and via networks to remote systems. On the left side, because these devices are used for capturing quantitative data, which among others types include measuring body fluids and pressures, e.g., blood glucose, and blood pressure. Another measuring device, left side and down in the figure, is a scale device ranging from red to green, which is a barometer for capturing qualitative data. A user can employ the device to explain feelings, for instance, how the person feels for the moment. If the person feels well, one of the green fields should be marked. Or if the user feels really bad, the orange field or the red field should be marked. This can give more inoformation about the user.

Another device, on left side, on top in the figure, is a road map over geographic positions of physical devices. The road map shows where the user-requested devices are for the moment. This is a so-called facility function, which the user can search and find available and applicable devices, for instance, blood banks, and necessary facilities. If it is emerange, this facility is necessary since it can be a life-saving facility.

On the right side of the figure, on the top there are databases, which are accessable from everywhere, via network. The databases contain data that are necessary to solve problems, carry out tasks and give advice. Depending on the problem, different databases will be used. Nonetheless, to get more information and a holistic view of the problem or task, websites, digitalised documents and social media can be utilsed. Often people around the world provide data and informtion about, e.g., symptoms and disorders, which can be of importance when finding a particular complaint and solution. These websites must be scanned using base words, using systems like the intelligent computer system called Watson [10], which has access to 200 million pages. Finally, the service on the right side, down in the Figure, is a cloud service that is keeping data and information about the users. Here, personal data and information can be stored and accessed when it will be used for solving problems or carry out tasks that are based on, e.g., personal medical information.

Often, when carrying out tasks, several of these devices are included at the same time to provide essential data/information, asyncronously, which is then used in the reasoning process. The figure, Figure 1, shows how devices are connected, with grey arrows, but the reasoning is centrally located in the user's own device. The user's device is responsible for asking and getting data and information from the surrounding devices, i.e. products and services. Nonetheless, it might trigger a chain of communication processes where an output of one device becomes an input to another devices, which output in turn become an input to yet another device.

4. Reasoning strategies

Reasoning is the process of drawing conclusions by utilising human beings' problem solving strategies. It is reasoning with facts and knowledge with given steps, using sets of inferences, or reasoning strategies. Typically these reasoning strategies include deductive, abductive, inductive, analogical, common sense and non-monotonic reasoning. There are also other commonly used reasoning strategies such as case-based reasoning and probabilistic reasoning.

Deductive reasoning [11] is when human beings deduce new information from logically related information, i.e., derive a specific conclusion from general premises. It uses axioms and implications to draw conclusions and the basic form of reasoning is the Modus Ponens rule of inference. The conclusions from deductive reasoning are guaranteed to be true because it implements logically valid reasoning. But it requires that the initial premises must be correct.

Abductive reasoning [12] is a form of deduction that allows plausible inference. Plausible is the conclusion drawn from available information with assumptions, but might be incorrect. From axioms and implications it can give a question as a conclusion.

Inductive reasoning [13] is to arrive at general conclusion from a limited set of specific premises. This conclusion applies for all cases of the certain type. If a few premises are true, it is induced that all premises are true.

Analogical reasoning [14] is when human beings form mental models of concepts through their experience used through an analogy to a known situation to understand a new situation of an object. They draw analogies based on the similarities and differences to guide their reasoning. A frame can represent typical features of some set of similar objects and can be used to understand new objects.

Common-sense reasoning [15] is when human beings learn to solve problems efficiently, through experience. They use common-sense reasoning to derive a solution. The reasoning rather relies on good judgments rather than on exact logic. The type of knowledge is called heuristic and is used to guide the problem solving in the system. Heuristic search or best-first search is often used as the basis for the reasoner.

Non-Monotonic reasoning [16] has dynamic truth values. If the state (true or false) is static during the problem solving, meaning the facts remain constant, it is monotonic reasoning. Sometimes, the facts change truth state during the reasoning process and the conclusion will have to take another value, this is non-monotonic reasoning. If the system is a truth maintenance system, which maintains a record on what caused a fact to be asserted, non-monotonic reasoning can support the system. If the cause is removed, the fact is retracted.

Beside these reasoning strategies, case-based reasoning [17] has been widely used. This reasoning is fundamentally different from the other artificial intelligent approaches. Instead of relying solely on general knowledge, case-based reasoning utilizes the specific knowledge of previously experienced, concrete problem situations, or cases. The reasoning procedure is retrieve most similar cases, reuse their solutions, revise the proposed new solution and retain case for possible future problem solving.

Probabilistic reasoning [18; 19] is a reasoning strategy that handles uncertainty. The probabilistic reasoning strategy is applied to find a natural extension of results from other strategies using uncertain statements. Problem-solving techniques are used for weighing the evidences and inferring conclusions.

It is difficult to investigate human being's problem solving. But reasoning strategies have been developed to mimic human problem solving, with mixed results. Among the different strategies, the deductive is one of the most common techniques. But one strategy is usually not expressive enough and a mix of different strategies can give more accurate conclusions. However, only few of these are interchangeable, e.g., deductive, inductive and case-based reasoning. These can be provided by the system as pre-defined strategies. To achieve a successful system, that is, one that is sufficiently powerful, it is necessary to provide the system the opportunity to develop a strategy. However, in modification of the reasoning strategy, the technique represented in a system is limited by the strategies that are usable in a system solving diagnosis and classification problems, i.e., deductive and inductive reasoning.

Conceptualisation can improve the semantic understanding of the formalisation of domain knowledge by applying concepts to rules or agents. If conceptualisation is applied, this can make the reasoning strategy easier to control and to change, and can also facilitate changing of the reasoning strategy in real-time. In addition to dealing with the contents of a knowledge base, the engineering must be improved to support a change in the reasoning. This makes it necessary promote comprehension of the reasoning strategy.

Utilising concepts in a time sequence and their relationships in a static and dynamic manner, respectively. Static presentation involves visualising the actual contents of the rule in the knowledge base to support changing the reasoning strategy. Dynamic presentation depends on the inputs the user inserts into the system, i.e., it is dynamic in the sense that it changes with the inputs, and the concepts and relationships corresponding to a specific conclusion. This can introduce quality assurance problems, since it can produce redundant, conflicting, subsumed or circular rules.

5. Reasoning for Cyber-Physical Systems

The reasoning, for the research in this paper, is the reasoning that is needed for data exchanged within a network of several integrated and connected devices and physical processes in the Cyber-Physical System. Thus, the reasoning must handle systems. However, each process is supposed to work as stand-alone device, with an input that produces an output without having a system-centeralised reasoning. Instead, the reasoning uses the output of the devices to infer conclusions.

Depending on the task to be carried out, several different resoning strategies can be applied. For instance, if the task is to find conclusions for a set of true data, then a deductive strategy will be used ($\forall x T(x)$ -> $R(x) \wedge \exists y T(y)$ then $R(y)$ *read For all Tornados, they Rotate and If there is a Tornado conclusively the Tornado Rotates,* which logially follows from the statement); if the task is to use a couple of premisses to induce a valid premiss as possible as conclusion, then inductive strategy will be used ($\exists x T(x) \wedge US$->$R(x) \wedge \exists y T(y) \wedge US$ then $\forall R(y)$, *read if it exist a Tornado and it is in US, it Rotates and if there is a Tornado and it is in US conclusively also this tornado will Rotate,* which it based on the observations so far).

If the task is to find possible explanations, abduction resoning will be used ($\forall x T(x)$ ->$R(x) \wedge \exists y R(y)$ then $T(x)$) *read If it exist a Tornado, it will Rotate and If there is a Rotation, conclusively it is a Tornado,* which is only one reason for the rotation.) This abductiive resoning is close to case-based reaoning, which will be used in CPS. The case-based reaoning is built on already known cases, such as ($\exists x T(x) \wedge \exists y S(y)$->$R(x) \wedge \exists x T2(z)$->$R(x)$,

read If Tornado and Swirl then Rotate and if Twister then Rotate)

The reasoning strategy to be used for a current data exchange in the Cyber-Physical System depends on the case to be solved. Also, it depends on the available data, devices and communication possibilites, as well as protocols, models and tools. In this paper, the inductive, deductive, abductive and case-based reasoning strategies are applied on devices, which support and preserve communication beween devices.

5.1. Deductive reasoning

Deductive reasoning in cyber-physical system is applied to provide specific conclusions, from general facts, to produce determined and trustworty decisions, that are deduced from the facts, from accessing the near envionment. Deductive reasoning allows reasoning from a user request. It can be provided with data and draws a conclusion with the data, at hand. The deductive reasoning implementations commonly use rules, static and dynamic, that are followed to reach conclusions. The static rules must be implemented prior to using the system, which requires that the domain or domains, in which the rules are applied, are known from the beginning. The dynamic rules, on the other hand, can be built during the use of devices and reasoning, announcing what data that must be included in the reasoning [20] and in which order.

The deductive reasoning uses these static and dynamic rules to deduce a conclusion for the given problem or task. The user provides a keyword(s) or request(s) to the system, which in its turn uses the input to request the different connected devices to provide output from the given input. These different outputs are facts that the rules use to provide conclusions.

The data are produced by the devices close to the user device in the environment, or via the Internet. Hence, the data is online all the time.The user device picks up the data but may or may not act on this data. This data is treated as premises, or facts, in the system.

The system traverses through all the rules in the system's knowledge base, and use the rules that are applicable. If all the facts in the rules are asserted as true, the rules will be satisfied and successfully presented as conclusions to the user. Hence, several rules can be applicable for the same task and then it is up to the user to select the rule to apply. The positive effect of rules, is the facts do not have to be provided in a particular order by the devices, i.e., if the facts are temporarly stored in a database on the device.

To give an example, the common situations presented in Figure 1, is used to show a siutation where deductive reasoning can be used. Keep in mind that smart CPS commonly contains both products and services so, when deducing a conclusion, the system might use devices that include product processes and services. One example of using deductive reasoning is when the user requests several different devices to carry out certain tasks, which, after they processes the request, will provide outputs. To make use of these outputs, deductive resaoning uses rules or frames to deduce a conclusion. All the facts and rules must be present, to be able to reach a conclusion. Deductive resaoning can also use the personal stored information (like user preferences) from the Mimi-Me cloud [7] to provide the conclusion. Unfortunately, if a fact is missing, the deductive reasoning will fail and, hence, another resasoning strategy must be used, such as inductive reasoning since it is a complementary reasoning strategy to deductive reasoning.

A real case example is when a user is moving around in an environment, the user might feel bad and want to request the devices to measure the blood pressure, and heart rate, and also request the devices to act according to the measurements. The devices produce outputs that the system use to provide a conclusion of what the user should do.

5.2. Inductive reasoning

Inductive reasoning in cyber-physical system is applied to provide general conclusions, from specific facts which support the user to get commonly provided data in the surrounding environment, considering a level of uncertainty. Inductive reasoning allows the system to use the incoming facts from the surrounding devices that are provided to system and applied in rules to infer conclusions. Since it is incoming facts may not user requested, not all facts may be known from the beginning but it is not a problem in inductive reasoning. Instead, when needed, the system can request for more data from the devices and the rules can be used to infer conclusions.

If the user is interested in an output from a device, the device will be invoked by the user's device, which acts upon a request. The user device, use the different devices outputs to infer a conclusion. If a unknown fact, i.e., an output from a device, i.e., product or service, needs to be found, the system will request the particular device for more data. This require that the device is known and the data it produces that are interesting to the user and the inference. The Mini-me device which is holding the personal information, can give support in this case. The personal information can be used to support searching and finding the device to request for data. Mini-me holds data from measurements and user preferences, which can be used as input data to the surrounding devices.

Again using the situations presented in Figure 1 as an example, the inductive reasoning is used to pick up data in the environment and provide a conclusion with a level of truthness. Not before the system, in the user device, picks up data, the surrounding devices will provide data necessary to provide a conclusion. These devices may or may not have the data that is needed but the inductive reasoning will work with the provided data. Hence, if a fact remains unknown, the inductive reasoning strategy can still give results. This requires uncertainty handling. The more that is known, the better result. However, if a fact is vital, the uncertainty should be high and vice versa. That means, it is important to know which data is important to reach a conclusion. The reasoning strategy handles the number of facts that are missing. If many facts are missing, the uncertainty is high and if only a small number of facts are missing, the uncertainty is low. But this does not correspond to the reality. Only one very signficant fact can change the whole situation. Nonetheless, if many facts are missing, it is very difficult to reach a valid conclusion.

The conclusions from inductive reasoning can be complementary to the results provided the deductive reasoning. In same cases, the conclusion deduced by the deductive reasoning can be used as a premise to inductive reasoning, to infer a conclusion but also the opposite. However, when using the conclusion made by inductive reasoning, the validity may not be the high and can make the deductive reasoning to reach wrong conclusion. That is not the case when a conclusion made by deductive reasoning is used in inductive reasoning.

A real case example would be when a user is moving around in an environment and the devices provide data to the user. The Mini-me can pick the data and start to infer a conclusion of what to do with the data and wheather or not, it needs more data to draw conclusion. If the requested data cannot be found, the system needs to draw conclusion with a level of uncertainty attached to the conclusion.

5.3. Case-based reasoning

Case-based reasoning in cyber-physical systems is applied to provide solutions to situations that are based on similar cases. The case-based reasoning has a broader range of application than deductive reasoning and inductive reasoning and can be applied in several different situations. The use of case-based reasoning allows the user device to have real world scenerios as cases and to match the external devices in the cyber-physical environment. The Internet can have libraries of cases for user needs, e.g., cases about medical conditions and assistance needs. These cases can be downloaded to serve a individual users needs.

A second class of cases can be downloaded for temporay user assistance. The users' preferences or abilities, as well as earlier cases can be stored in Mini-me [7], and fetched and used when new similar situations occur. For example, suppose the user is visiting a health care center, there can be a whole set of possible cases that can be availible for the place. These cases can be filtered by a users preferences or abilities. Supposedly, the user happens to like something particlar in the center, then cases related to these interests can be selected and can help the user find these pieces of interests.

A third possibility is the case when the cyber-physical world makes service offers to the user. Then, user's device searches the web for scenerios (cases) that correspond to the service, to be able to reason about the service. In this situation, the offer itself may be unknown to the user's device, so cases can represent capabilities of the offered service. However to make use of the cases, they must include required inputs for the service to utilise the service. Moreover, to make sure that the service is genuine, the cases must validate the offer, determined if is the service is well formed and a wanted and acceptable service. The case should handle negotiation [7] when dealing with the service.

Case-based reasoning allows abduction to be applied in addition to deduction and induction. The case being applied provides a model of the service being offered. The case may match known facts and, therefore, be applicable, immediately. However, when the case is not a complete match, abduction allows the system to assume the missing parts or to use deduction or induction to supply missing details.

When pure abduction is used, the system may conclude that a precondition, that is part of the case but not known to be satisfied, can assumed to be met. This assumption of the precondition can lead to future reasoning. For example, in a medical case several symptoms may be present, but one symptom, or more, may be missing. This could lead to the system attempting to establish the missing symptom using abduction reasoning. Or, the abduction could lead to the conclusion that the symptom is probably present and can be assumed. The abduction's choice will need to consider the facts: is the missing part of the case more sigificant than the part that is known, or is the assumption commonly true. Using common-sense reasoning with heuristics can enable the system to carry out this task.

5.4. Probabilistic reasoning and analogical reasoning

One of the most interesting reasoning strategies in cyber-physical system is probabilistic reasoning. Probabilistic reasoning can be combined with deductive reasoning to handle uncertainty situations. The uncertainly is employed in truth tables to give probablities of what is likely to be true. Hence, it is the formation of probablity judgements. It is also the formation of beliefs about the likelihood of outcomes and the frequences of events. Often Bayesian probablity [21] is applied to get the probability value of data. The outcome from probabilistic reasoning can be calibrated to be coherent with the expected and realistic outcome. This probabilistic reasoning can be useful guide to likeligood of events.

Analogical reasoning uses analogies, based on the similarities and differences, and metaphors to understand new objects and new situation of an object. By utilizing one device may give an idea of how to understand what that device can be used for in another situation. Hence, the analogical reasoning should be used among devices in the CPS. Another example of analogic reasoning is to reason about a new case using existing cases resulting from case-based reasoning.

Both probabilistic reasoning and analogical reasoning are very interesting and important strategies, for handling uncertainty of conclusion as well as handling devices in new situations. In induction probablisitc reasoning is central to the generation of conclusions; analogic reasoning is central to extending case-based reasoning. There is a risk though that the user of conclusion may take it more serious than the uncertainty shows. For example, if the probabilistic reasoning is used for measuring the heart rate and it claims that it might be a heart rate failure with the chance of 15%, the user will have hard time interpret that conclusion. When it comes to analogical reasoning, using the measuring device for another person, for example a child instead of an adult, or an animal, the heart rate will be much higher than for an adult and the conclusion will be out of scope.

6. Related work

There are not many who have worked with reasoning strategies and cyber-physical systems in the way that we do. Commonly reasoning strategies are used as verification and validation tools in cyber-physical systems [22; 23]. There is one paper that discusses a first step to provide a framework for networked cyber-physical systems that combines distributed reasoning and asynchrionious control [24]. The proposed framework enables recasting information collection, control and decisions problems as logical problems centered around facts and goals. Facts represent senosor readings; goals represent queries for information or requests to the system to perform certain actions. Our aim is not to steer the devices to perform certain actions, instead it is to use the output in decision-making to infer data, information and knowledge that can be used by a user as decisions.

7. Conclusions

This paper presents reasoning strategies for cyber-physical systems that are used to extract and combine data and information. The reason for applying the strategies is to provide an intelligent behavior from users point of views. The reasoning strategies utilize the users' needs, using personal preferences and needs, as a starting point and, then, provide an environment that gives personalized support.

To make the components of the systems act intelligently and according to users' needs, the cyber-physical systems use the reasoning as chains of performances of different components to be able to make use of the components in the surrounding environment. The reasoning includes collecting sensor data, finding key concepts in the data and drawing conclusions that cyber-physical systems can use to control the components surrounding the users.

The reasoning we focused on in deductive reasoning strategy, but all should be provided by the cyber-physical system. There are challenges though. For example, there is a range of different components in a system where each has particular communication input-output and its own set tasks, which provide particular challenges associated with controlling or predicting the behavior of such systems.

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