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Formal Modelling and Verification of Health Care System Through Petri Nets

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ABSTRACT

Now a day's, research has focused on the health care system to make people's lives easier and more manageable. The primary objective is to extend health care systems and services across different domains while assuring connectivity and automated exchange. The health care system, modelling, and deployment are the focus of the recent study. However, several issues still need further investigation, particularly in flexible modelling, extendable implementation, and privacy. Formal verification and modelling using a formal analysis indicated several results. This contribution presents a realistic paradigm for the healthcare system, particularly for emergency services. The proposed model's correctness is confirmed by the results obtained. The first step is to generalize a meta-model to instantiate the model for a variety of services, not just health care. Our ultimate goal is a health care system that may be used in various ways. Extensible, secure services are built into the system, which can be used in several situations.

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1. Introduction

The rise in chronic diseases has poured considerable change into health care systems. There are body sensors that can help reduce the costs of these products. Sensors can be used to keep a check on older people who have long-term diseases from afar and let them live more independently. There are a variety of various ways to employ body sensor networks. For example, when during exercise, body blood pressure will rise. It might also be a symptom of a significant medical problem if blood pressure climbed while were at rest (Andrews, Payne, Romanovsky, Didier, & Mota, 2013). There may be a lot of different sensors that need to exchange with each other. Sensors may not only measure physiological parameters but also how the body moves. As the number of sensors increases, so will the complexity of their interactions. Many different body sensors at home can communicate to the health controller, a camera sensor, and cell phone only if the body sensors detect that there might be a medical emergency, for as when the patient is lying down in the kitchen if the patient is cleaning the kitchen, taking something from the ground, or having an accident. If the software identifies an emergency, the hospital staff is alerted. They take a look at the data and decide the next step. The patient's mobile phone notifies them how their body is doing and how the sensors are doing. If there is an emergency, the patient's phone can send an alert, and the patient can also report if the alarm was false (Wassyng).

In several nations, the safety of sensors that collect health data is mandated. It is more challenging to acquire a home health care system because of the varying criteria for different parts. On the other hand, sensors are subject to far fewer resource constraints than smartphones, cameras, or desktop computers (Atanasovski et al., 2018; Méry & Singh, 2013). Depending on processing power and communication costs, additional security mechanisms may be required across the system. For example, physiological data was utilized to develop a quick and straightforward method of setting up a key for body sensors. However, medical professionals or an analytics engine may receive physiological data from the home health system. Figure 1 shows a representation of a prospective home health care system. The physiological data may be relayed to an implement that could deliver drugs directly to the patient's body.

Figure 1: Influence of Health Care System

A rigorous method is needed to ensure that the same physiological data isn't being used for multiple security and information assurance purposes. Using a formal technique helps ensure the accuracy of the information sent to medical personnel and the actuators responsible for dispensing medication (Swan, 2009).

Formal verification can be proven or disproved if a system model is correct. Some of these approaches may be built on the mathematical model, which illustrates several ways the system might behave (Faconti & Massink, 1998). Specification languages, such as "property specification," are used to document the system's accuracy criteria. When the model's properties are checked, it's verified if it's acting as expected. A mathematical model of the system is used to provide formal proof of the system's correctness (Ruiz, Contreras, & Garcia, 2020). When demonstrating the model's behaviour, formal verification is the best option. The algorithm examines all of the system's conceivable states to check if they all can achieve the required attributes. After finding any form in which a rule, the model checker explains how that state came about. Figure 2 demonstrates Factor include for Improvement in Health in formal verification, theorem proving and bounded model checking are two of the most frequent techniques.

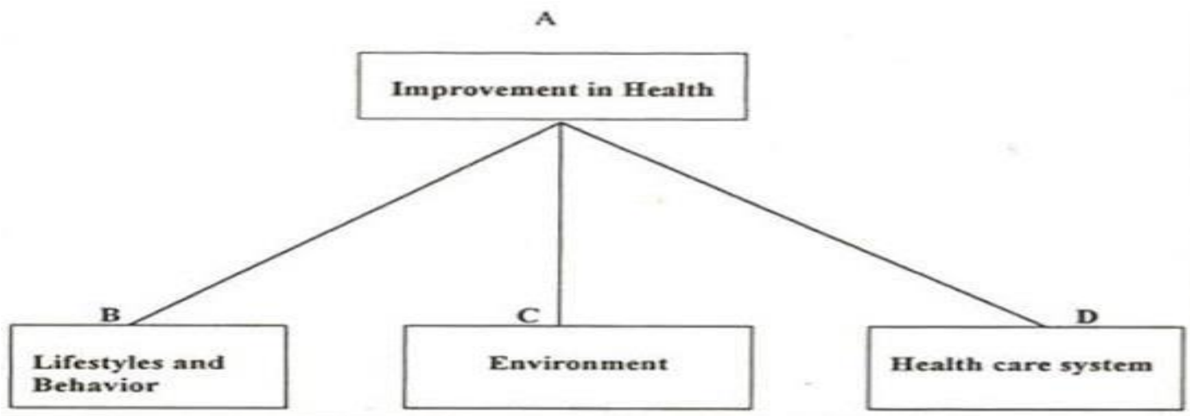

Figure 2: Factor include for Improvement in Health

2. Objective and Motivation

The safety of these vital services is predictable by those who use them in the healthcare system. Doctors and nurses are held in high regard for the privacy and security of their patient's medical records. As a result of the system's complexity, a model typically consists of much smaller components than the entire thing. Neither a "standard" construction method nor a "formal" means to display all of these models exist. Modelers must choose a authoritative model to express and analyze the system they are modelling and the purpose for which they are doing so. Next, implement a formal notation based on set theory. Thus, build relational structures of arbitrary complexity using set theory notation while retaining analytical capability. Modelling notation is presented and explained as the model is constructed.

3. Related Work

A body sensor network monitors the aged patients' health with long-term ailments. The home health care system's safety and criteria result from a great deal of effort. In this research, Singh and Muthukkumarasamy (2008) demonstrate how the health care system can benefit from genetic design. Sources between body sensors that do not already know each other can be generated using physiological data. Using a model checker ensure that the protocol works appropriately in the system by creating a model of the behaviour tree and testing it.

Sahoo et al. (2018) proposed that these stack DRAM modules have been used as the last level cache in some of the most popular processors. The bandwidth and latency of these stacked DRAM modules are far superior to those of off-package DRAM modules. Recent studies on DRAM caches have yielded many new ideas for improving system performance and power. DRAM system timing and cache functioning are intertwined in this issue. Hence, verifying their correctness would be difficult without extensive modelling and testing of these ideas. The baseline for the shared cache and the controller model is what call the "base model." As a result, model checking ensures that the new version is safe to live with and on time.

CPS (Cyber-Physical Systems) integrates discrete-time computers with continuous-time physical-world items, often wirelessly linked by (Tan et al., 2013). Wireless safety important CPS (control, healthcare, etc.) must remain secure despite communication issues. Proper-Temporal presenting is the only rule their research discusses regarding safety (PTE). CPS design patterns can be described and analyzed using hybrid automata and devised a new lease-based design pattern with closed-form configuration constraints. The method successfully protects PTE safety, which prevents the physical environment from interfering with specified designs. According to a case study, laser tracheotomies wireless CPS is safe and can handle communication issues.

Floods during the monsoon rains are expected in Pakistan, and they have a significant impact on a large number of people. For many people, these are their primary sources of income. Torrential rain falls during the monsoon season, and the snow on the northern glaciers quickly melts due to global warming. It is because of these circumstances that floods take place. Detecting floods early and working out their size helps people avoid them. They save money and reduce the number of deaths as a result. Most people perish because they lack quick, real-time, and accurate information about the places at risk and the floods' strength, pace, and direction. As a result, the suggested strategy relies on formal modelling and verification. There are several sensors in each flood detector. The research aims to develop a WMR SoS based on formal flood warning, monitoring, and rescue.

Marjanovic *et al*. 2019 demonstrated that workflow systems for business processes are time-based to mimic the actual world accurately. Especially true if altering the process from the model would be prohibitively expensive, risky, or even illegal. Work includes the permissible system, aviation maintenance, and handling dangerous materials. It is discussed in the study how production operations can be modelled using time. The rules for checking the time limitations are provided. A new notion called "duration space" is added to make it easier to see some of the time limits. The shortest path partitioning algorithm and the Critical Path Method (CPM) are two different sorts of algorithmic processes. Both of them can be summed up in a way (CPM).

Zeng, Lu, Liu, Duan, and Zhou (2014) proposed that Cross-department business processes have become increasingly complex. It is more challenging to model and analyze things when separate departments work differently. Cross-department processes cannot be formally modelled and checked when there are varied coordination patterns between several departments, to our knowledge. Resources and messages are added to a WF-net model that has been previously exhibited. Then, a formal model of tasks is presented, and the connections between them are also shown in the technique.

Semi-formal and formal methods are used in research to model and verify embedded software security, which is required by today's more stringent regulations by (Hu, Zhuang, & Zhang, 2020). ZMsec (Z-MARTE security model) is shown to define three categories of software: security use cases, static structures, and dynamic behaviors. A depth-first technique is used to generate an understandable ZMsecSD for model checking. When it comes to modelling and verification, this study builds a prototype version of the ZMV. The last example discusses an embedded software example named ZMV, which demonstrates and validates the security modelling and verification method applied in research.

Souri and Norouzi (2019) demonstrated that the Internet of Things (IoT) has risen to prominence in recent years as a tool for connecting things and people in new and more valuable ways. Increasingly, IoT applications are being processed via industrial and enterprise IoT systems. Also, formal verification methods must be applied because intelligent devices can't have system failures in safety-critical situations. As a result of the study, the standard verification methods currently employed in IoT applications are provided.

Research by Brailsford, Harper, Patel, and Pitt (2009) on simulation and modelling in healthcare is classified in various ways in the research. The purpose of the study was to examine how frequently different operational research modelling methodologies were utilized in health care. They shed light on how much progress is being made in many fields, revealing crucial connections and omissions in work. It is also a generic and methodical strategy that may be utilized in other domains and with various information sources in healthcare modelling.

Some researcher suggested that an approach for developing intelligent healthcare systems is required to meet needs. A large portion of the field's study relies on manual methods, incorporating a wide range of cutting-edge technology ideas. Using the Internet of Things (IoT), Finite Automaton, Unified Modeling Language (UML), and the VDM-SL formal method created an automated formal model of an e-hospital emergency management system by subsequent the instructions. A few of the system's functions include patient registration, triage and e-prescribing, payments, and discharge.

In a System of Systems (SoS), the constituent systems each have their administrators and operations and are collectively referred to as "Constituent Systems." It's possible to have an SoS directed, acknowledged, or co-created by (Seo et al., 2016). Depending on the sort of SoS, the degree of control over the CSs will differ. Many researchers have attempted to model and verify SoS-level goals, but they haven't given much attention to how different SoS are characterized and realized during the process. So that response to mass casualty incidents is an example of a distinct type. PRISM's probabilistic models model the various kinds of SoS, which can quantify the uncertain behavior of an SoS, and perform statistical model checks to ensure the models' accuracy.

Abbas, Zafar, and Ullah (2016) Suggested that Smart Traffic Monitoring and Guidance Systems include LEDs and bridges. Rules violations and traffic congestion are monitored using LEDs, and the central hub communicates with sensors to notify the server of the traffic condition. It communicates with the system through the use of Wireless Sensors and people. When someone violates the regulations, additional sensors send out a challan. Secondly, the LED component informs the public of the current traffic conditions. The third function of the Bridge component is to serve as a central communication hub for the model's various features and to perform server-side updates. Model's parts have a formal specification written in VDM-SL. To describe complicated systems, VDM-SL is a formal language. The specification was validated, checked, and analyzed using the VDM-SL platform.

3.1. Petri Nets

It is possible to utilize Petri Nets to describe and analyze non-deterministic, parallel, distributed, stochastic or concurrent systems formally and graphically. Using Petri Nets to demonstrate how things function is possible isn't ideal for modelling complex systems. The definition of data and functions can be simplified using Petri Nets. Study effort benefits from Petri Nets, helping us understand how our system functions.

4. Material and Methods

There are formal methods for verifying a system's correctness against its specifications and restrictions. Formal verification is the name given to the applied method. Different aspects of the verification process are examined. It is not easy to ensure that hardware systems perform effectively without extensive testing with many states. Things like model checking are frequently used to ensure that they are correct. If a model fails to match a user's requirements, it is re-created differently.

4.1. Requirement Indemnifications

In every formal verification process, requirements serve as the first stage process. The syntax of a standard language, like that employed in mathematics, is used to write them down in properties or axioms. These axioms or attributes are intended to show both the behavioural and non-behavioural aspects of the system. Other components of the system that aren't behavioural include security and safety policies, performance, and other system elements (Jørgensen, 2003; Kotva, 1988).

Table 1
Requirement Table for the Health Care System

Places	Transitions
P1: Patient	T1: Patient arrival
P2: Reception for Registration	T2: get token
P3: check by an attendant	T3: forward by doctor
P4: check by a doctor	T4: medical treatment
P5: report verification	T5: patient-reported by doctor
P6: report sent to a doctor	T6: admin in ICU
P7: test for the disease	T7: report stored by an attendant
P8: discharge patient by the doctor	T8: discharge process

The non-behavioural elements of the system are about how it functions and values. Regardless of how bright the light from the sun is outside, the smart home has to raise the window shutter and turn off the lighting to simulate the situation. Table 1 demonstrates the Requirement table for the health care system. The use of temporal logic is a systematic approach to express formal requirements.

4.2. Design Flow for Proposed Approach

It would help methodologies, techniques, and tools with a solid mathematical foundation perform formal modelling and verification. Different levels of traditional approaches are utilized at various stages of the development process in complex systems like SoS. Suppose we need to improve and test the system rigorously.

4.3. Petri Nets Models for the Health Care System

The generic design has many advantages over UML, state charts and system modelling. The following are some of the assistance strategies. Figure 3 demonstrate states and transitions for the proposed model.

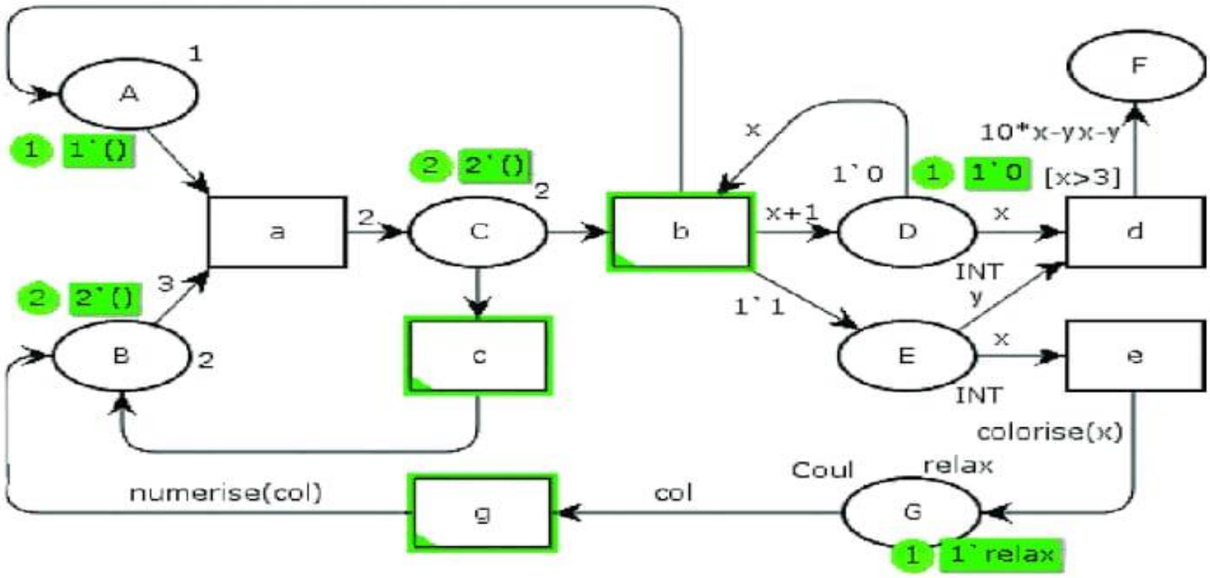

Figure 3: States and Transitions for the Proposed model

- It is possible to focus on the design and complexity of particular criteria without perturbing the fine details of other requirements. It is possible to complete each of the tasks alone.
- Because of this, the design behaviour tree is responsible for determining the structure and behaviour of individual components.
- The strategy first focuses on identifying gaps in requirements to detect cracks in behaviour. The direct translation of requirements into the design makes it easier to spot and fix design flaws. Figure 4 represents tokes and states

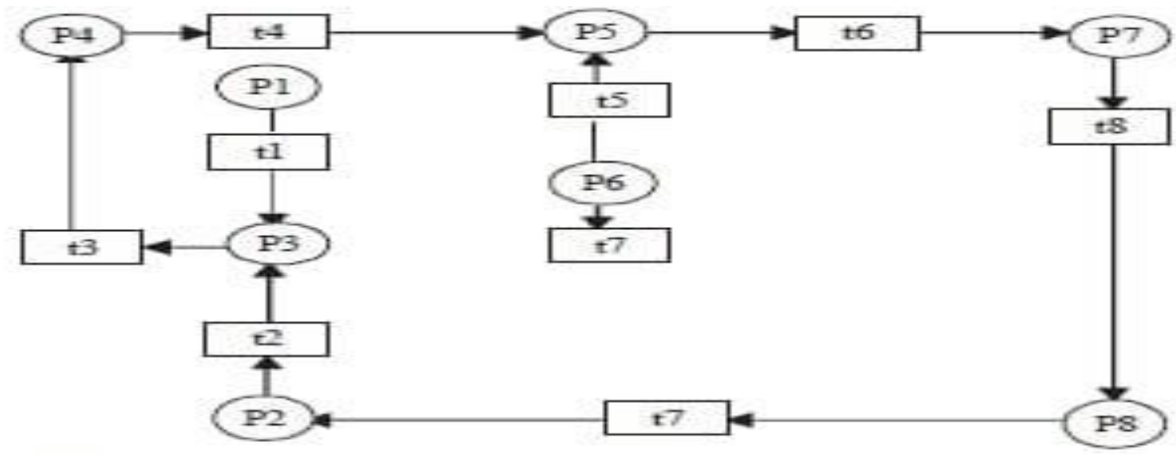

Figure 4: Tokes and states used for the health care system

Design modifications should be linked to changes in requirements, and linking should be automated. Figure 5 demonstrate the Petri Net model before simulation. The genetic design relies heavily on behaviour trees, which play a vital role. Examples of Behavior Trees include the exchange of knowledge and the transfer of control among individuals, groups, or things, as described by Dormy (Al Hamadi, Gawanmeh, & Al-Qutayri, 2014; Manataki, Fleuriot, & Papapanagiotou, 2014; Pirouz, Nejad, Violini, & Pirouz, 2020). Genetic design is one of them. It is possible to create graphical models according to the original specifications (Giorgini, Massacci, Mylopoulos, & Zannone, 2004; Schmitt, Hoffmann, Balser, Reif, & Marcos, 2006). Models are available to ensure security mechanisms are working correctly in a complex system.

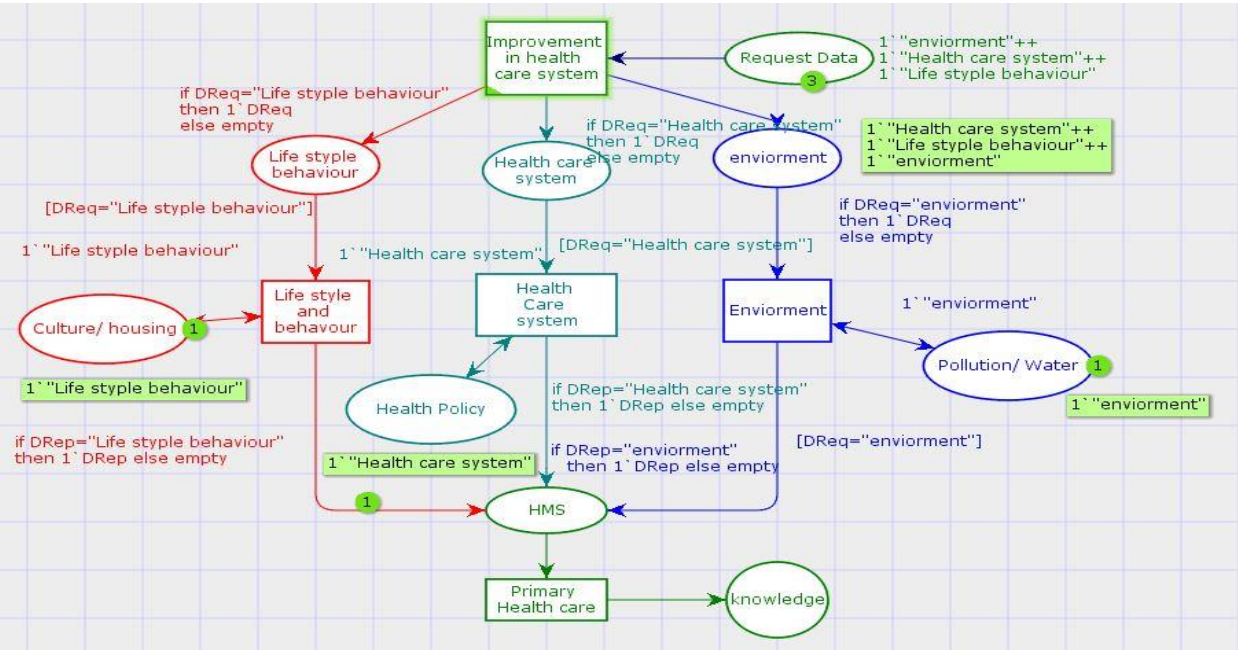

Figure 5: Petri Net model before simulation

Keeping track of how sensed data is used in a home health care system is difficult due to many components. Monitoring how perceived information is used in security procedures is much more critical. Examples of such protocols forbid the transmission of sensed data in the open or to an untrusted third party [25]. These rules are unnecessary in other protocols. Start by constructing behaviour trees based on the needs identified. Figure 6 displays the Petri Net model after simulation. Then integrate the behaviour trees, update the architecture, create components, and design them. Afterwards,

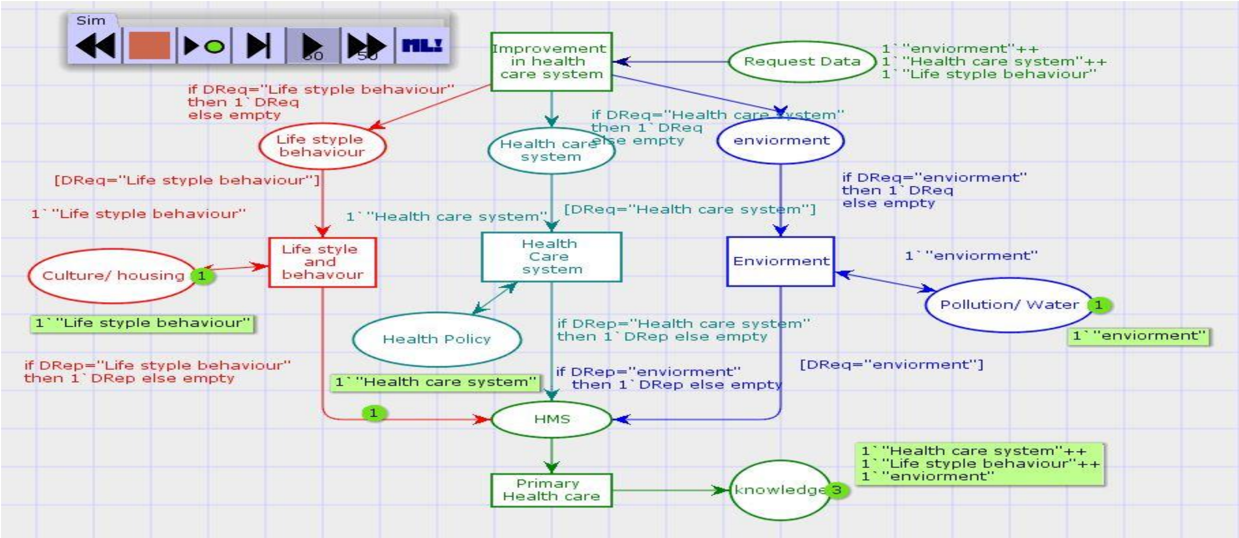

Figure 6: Petri Net Model After Simulation

5. Results and Discussion

In addition, formal checks are performed to ensure that they act according to company policy. The pattern can be explained since the minimum formalism provides some behaviour modelling. However, black-box modelling plays a more significant role in the early stages. On the other hand, this position necessitates a great deal of time and effort.

White boxes can be modelled using statecharts. Although it's easy to find state maps to make things more complicated, they don't cover all of the possible routes in terms of mathematics. The Event condition is the most common way to model intelligence.

In most cases, all of the strategies are used to take action. Formal verification must not involve artificial intelligence. Solutions modelled need utilizing some variation of temporal logic. To be clear, most of these strategies collect data on how and what people identify themselves and perform to create user models. Because of the complexity and ambiguity of human behaviour, only a few strategies exist for simulating real-world user behaviour. Considered at various methods for modelling strategies, all of which consider how the instruments interact. However, just a few techniques are employed to ascertain how each gadget functions. Most of these approaches model control; however, their vantage point differs from the other methods. A user's perspective, a piece of equipment, and the surrounding environment or context all play a role. Seven of the context-modelling strategies examined consider how the user moves before making any decisions.

Furthermore, it appears that strategies for identifying and acting on users cover most of the ground in terms of interaction modelling. What can be done is a significant aspect of interaction modelling, based on these. Whenever they model and control the health care system, they keep one or more aspects of it in mind. They are primarily concerned with the end user's experience. Parts can be modelled in many ways, but there aren't many methods to model them all. As a result, it's understandable that they don't perform any consistency checks. There have also been seven methods found to check on the behaviour of users. Healthcare systems that have been modelled cannot be dynamic or responsive.

Health care is critical because it must be viewed as a whole, not just as an individual component. A model like this is vital to future research, and it cannot be ignored in any way. Some techniques can also be used to ensure that the devices are compatible. Because of the increasing complexity of devices and the intricate way they operate together in a system. However, this form of modelling is critical because of the mounting requirements.

According to the information, almost all strategies are tested using device interaction and control verification. It made sense that they would be subjected to this form of testing. Real-time and probabilistic testing isn't as standard in the methodologies examined. Health care scholars should look at these areas, as they are critical but understudied. According to the research, some strategies can be improved by including additional components and data. According to the study, eight procedures are manual, eight semi-automated, and only one claims to be entirely automatic. Since the healthcare system is so intricate and requires complex modelling and verification, it is difficult to say that these procedures are entirely automated. The only genuinely automatic method is based on rules and is not intuitive.

6. Conclusion

Abstraction is another approach that may reduce the number of states in a model. It's important to remember that modelling still has a place in the implementation process since it creates generic dictionaries and communication procedures that are quite useful. According to our study, most of these strategies use formal modelling and formal verifications. Black-box modelling, which isn't apparent, was also employed less frequently in the practices. Ambient Calculus is utilized when both the user and the context are essential. Model checking is used to perform formal verification. They argued that no technique is fully automatic and covers all aspects (such as modelling the context, user, and healthcare system equipment). As a result, it's safe to say that modelling and verification of health care systems have an elongated technique. Because complicated scenarios and components for modelling and verification are challenging to model and verify, current scholars pay little or no attention to them.

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