A SYSTEMATIC REVIEW OF CONTEXT INFERENCE APPROACHES FOR USER-MOBILITY FACILITATION IN SMART HOMES: LOCATION-CONTEXT VS LOCATION INDEPENDENCE

Phumzile Nomnga

Department of Computer Science,
University of Fort Hare,
Alice, 5700, South Africa
pnomnga@ufh.ac.za
http://www.ufh.ac.za

Khulumani Sibanda

Walter Sisulu University, Eastern Cape
South Africa
ksibanda@wsu.ac.za

Abstract

Several context inference approaches, which deployed Convolutional Neural Networks (CNN), Long Short-Term Memory (LSTM), Hidden Markov Model, Conditional Random Fields (CRF) to mention but a few, have been employed in research to facilitate user context inference in specific smart homes relying on situational information which includes location context. However, considering the realities of heterogeneity and idiosyncrasy in the smart home domain, relying on location context to infer user context towards achieving adaptability and home automation is poised to present technical limitations when a user moves from one intelligent environment to another due to location variability. This paper seeks to address a pertinent question, what techniques and approaches could be employed to infer Activities of Daily Living (ADL) over heterogeneous pervasive intelligent environments without making extensive use of location context which varies from one home to another? To this end, a systematic literature review of smart home inference approaches for personalized home configurations was conducted to understand the efficacy of the existing solutions to facilitate user mobility in the smart homes domain. This standalone approach combined the descriptive and critical review types and followed a scoping review procedure to extract relevant information from existing literature and present a complete overview of the state of literature. Literature shows that various inference techniques still rely on the location context and user mobility is yet to be fully realized through context inference approaches.

***Keywords*: machine learning, human activity recognition, user-mobility, adaptability, location-independence.**

1. Introduction

Provisioning of activity context-aware services in the context of smart homes has always been a critical service since the emergence of ubiquitous computing. At the core of it is the drive to facilitate practices and increase convenience. To this effect, designing and implementing enabling models, algorithms and methods has been the focus of various researches in the past couple of decades. The standalone-based and service-oriented architectures-based (SOA-based) systems have also been explored in activity recognition and services interventions. Additionally, [Chen et al., 2013] discussed that "ontologies have been adopted as the unified conceptual backbone for modelling, representing and inferring activity context, user activity profiles and contexts." The need for activity recognition and services is greater than ever before considering the exponential

growth in the amount of data traffic today as envisioned by Cisco visual networking index projections entailed in [Cisco Visual Networking Index 2015]. The increasing number of connected devices particularly in the context of smart homes sets the scene for user mobility across the domain. Users do not only transition between devices and machines but homes too. In a connected society characterized by connected everyone and everything, it would be of great convenience to users to transit and adapt to discovered smart homes with their activity profiles and personalized contexts. Inferring user behavior from activity profiles and contexts to encountered smart homes in a seamless and dynamic way would be greatly essential for computational efficiency. This article focuses on the efficacy of existing solutions that have been used to build home-automation assistance systems. Central to this work, is to understand the capabilities of existing solutions to learn user behavior and use it for system composition in newly encountered assistance systems when a user moves from one environment to another.

This literature review is conducted in view of the knowledge of the potency and efficacy of potential solutions that could now be employed to infer user-behavior towards facilitating user-mobility in the smart homes domain. One potential solution is deep learning and machine learning techniques. [Oladipo et al., 2022] explains that "the execution of deep learning experience is strictly dependent on two stages, known as the training phase and assumption phase." They further explain that "the training phase entails labeling and evaluating the matching features of massive amounts of data, while the assumption phase entails making conclusions and using prior knowledge to mark new unexposed data." Appreciating the heterogeneity and idiosyncrasy that characterizes the smart homes domain, the deep learning experience ought to be stretched to help achieve the ideals of ubiquitous computing, particularly user mobility. The user behavior, observed from ADLs, can serve as input data in a state vector in hidden units which will be utilized to compute outputs as the process is explained in [Mosavi et al., 2020]. In anticipation of significant heterogeneity in newly discovered smart-homes systems in terms of devices and application data amongst others, the Long Short-Term Memory (LSTM), a Recurrent Neural Network (RNN) method, can be leveraged for decision making on input entry to the neuron and to remember what was computed in the previous step. This is a critical component of the model in managing the process of inferring activity context, user profile and contexts in newly discovered smart-homes systems. According to [Chen et al., 2005] smart-homes systems are not cast in stone in the sense that, each smart-home may have unique "information about a location, its environmental attributes and the devices, objects and software agents that it contains" which are different from others, probably an ideal element for using prior knowledge to mark new unexposed data from the newly discovered environment.

Another potential solution is the ontological modelling which has been tried and tested, but not without using location context. As articulated by [Ngakam et al., 2022] "the need for expressive modeling and support for contextual reasoning makes ontologies a primary tool for contextual modeling." Ontologies have been extensively used to address challenges of contextual reasoning, knowledge sharing, context classification and context dependency amongst others. Some of these ontologies are domain-dependent, specializing in modelling domain-specific concepts to provide home automation assistance systems. Typically, is the solution named ComfOnt, which "aims at providing inhabitants with the possibility of having personalized indoor comfort in their living environments and at helping them in scheduling their daily activities (energy-related) requiring appliance" [Spoladore et al., 2019]. This paper sought to understand, to what extent have these potential solutions been implemented, individually and/or combined, to facilitate seamless adaptivity of users in newly encountered assistance systems. To this end, this paper considers the home-automation requirements and their subsequent formal representation in an ontology and discuss this in the context of ubiquitous computing and user mobility across smart homes.

The remainder of this paper is organized as follows. The next section presents the smart homes and user mobility challenges. The third section presents the research methodology followed in this paper. The fourth section presents a review of selected papers. The fifth section is dedicated to the finding and discussion. Finally, a conclusion of the work presented in this paper is presented.

2. Smart Homes and User Mobility Challenges

Existing approaches such as [Chen et al., 2022] relied on location to characterize services that should be automatically provided to the user based on user behavior in an environment. In practical applications, human activity recognition is seriously affected by the location variations, which is one of the prominent problems to be solved urgently as stated by [Ding et al., 2020]. In some cases, "activities of different users with diverse habits in different environments and locations have not been included and investigated" [Ding et al., 2021]. Modeling and reasoning of context in smart homes, through ontological and/or probabilistic approaches, have in the past relied on location context for service discovery and context-aware service provisioning. Many of such solutions were only designed and confined to one unique environment (location) for testing, implementation and deployment and never been deployed to facilitate user adaptation for nomadic users. Because of this computational challenge, an ontological-based model to seamlessly integrate learned user behavior into newly

discovered smart-homes is needed to support users on the move with negotiating for service in encountered assistance systems. Effectively, users do not necessarily have to be in a particular physical location or place in a house as a requirement to perform a particular activity in a smart-home due to realities of heterogeneity.

3. Research Methodology

This study conducted a standalone systematic literature review, combining the descriptive and critique review types, to respond to the question of location context centrality in ADL inference in the home-automation assistance systems. [Xiao and Watson 2019] defines a descriptive review type as a review that "examines the state of the literature as it pertains to a specific research question, topical area, or concept." To this end, a scoping review procedure was followed which emphasizes on the need to "extract as much relevant data from each piece of literature as possible, including methodology, findings, variables, etc., since the aim of the review is to provide a snapshot of the field and complete overview of what has been done" as explained by Xiao and Watson. Towards this end, papers on inference techniques, location-independence, and context awareness relating to smart homes were collected from some prominent online databases in the computer science field, namely ScienceDirect, ACM, IEEE Xplore and MDPI. To narrow down the search, keywords derived from the research question were used, namely inference, location, ADL, and context-aware either as separate terms or combination of two or three terms. A combined total of 210 papers across the four (4) databases were downloaded from which abstracts were examined against the set criteria of which 132 were eventually excluded. The explicit exclusion criteria considered papers that addressed context-awareness or HAR in smart homes but did not address any techniques to infer data towards facilitating user-mobility in smart homes. The explicit inclusion criteria considered papers that discussed supervised machine learning approaches to infer ADL to adapt context-awareness during user-mobility. Effectively, 78 papers were fully examined as having met the criteria of which 23 papers were selected to inform this study. The 23 selected papers considered in particular the ADL inference techniques/approaches and resultant technical solutions. Additionally, a critical review which "involves comparing a set of literature against an established set of criteria" as defined by [Xiao and Watson 2019] was followed. Effectively, this study examined the location data requirement in context-awareness in comparison to the user-mobility requirements in the broader context of ubiquitous computing.

4. Review of Selected Papers

Towards providing a theoretical analysis in the end, the review of selected papers is presented in three categories of which their findings are integrated during interpretation phase in the discussion section. The three categories consider existing research on three components deemed critical for facilitating user mobility in the smart homes domain, namely the deep learning and machine learning algorithms, location-independence and context-awareness approaches. Effectively, category 1 considers the existing research on deep learning and machine learning approaches for location-based personalized home configurations to future home systems. Category 2 deals with various inference approaches to facilitate location independence and adaptivity in Smart Homes. Category 3 considers the existing research on context-awareness approaches to facilitate location independence and adaptivity in Smart Homes. To this end, a list of selected papers for each category under Tables 1-3 is presented entailing the researchers, overall aim, (methodology, context-awareness approach, or inference approach/technique) and solution/contribution of each article. Subsequently, a comprehensive review of the selected papers is presented below Tables 1-3, with the aim to understand the current research advances with respect to user mobility in the smart homes domain.

Table 1: Existing research on deep learning and machine learning approaches for location-based personalized home configurations to future home systems.

Researcher(s)	Overall Aim	Methodology	Solution/Contribution
Schmid, J., Schneider, M., HöB, A. and Schuller, B., 2019	To propose a throughput prediction method that focuses on a location independent approach.	In order to compensate the missing positioning information, mainly used for spatial clustering, their model uses low-level mobile network parameters, improved by additional feature engineering to retrieve abstracted location information, e. g., surrounding building size and street type.	Thus, the major advantage of their method is the applicability to new regions without the prerequisite of conducting an extensive measurement campaign in advance.
Ding, X., Jiang, T., Zhong, Y., Wu, S., Yang, J. and Xue, W., 2021.	A human activity recognition method adapted to different initial states. Furthermore, they solve the accompanying issue of the small sample size sensing, obviating the need for the cumbersome wok resulting from the massive data collection.	The experiments demonstrate the feasibility and excellent performance of their method, which could recognize human activities with different initial states as the training data.	They present a novel human activity recognition method based on one-shot learning, which realizes adaptive initial state sensing with only very few samples for each activity. To address the problem of initial state-independent sensing, they firstly utilize the neural network to embed the raw CSI data to the separable feature space.
Ding, X., Jiang, T., Li, Y., Xue, W. and Zhong, Y., 2020.	A location independent human activity recognition system based on WiFi named WiLISensing. Additionally, authors demonstrated why transfer learning is a better solution to this problem.	The system mainly consists of three parts, which are data prepare, model build and finetune the model based on transfer learning. Due to the noisy raw data, a denoising method is followed. To enlarge the dataset for deep leaning, they provide the way of data augment. To achieve position independent perception with as few samples as possible, a human activity perceptive method based on transfer learning is proposed.	Extensive experiments have been carried out to show that WiLISensing could achieve promising accuracy above 90% in recognizing six activities and outperform state-of-the-art approaches.
Ding, X., Jiang, T., Zhong, Y., Huang, Y. and Li, Z., 2021.	A location-independent human activity recognition system based onWi-Fi named WiLiMetaSensing.	Extensive experiments have been conducted in an office with 24 testing locations. Extensive experiments are conducted to explore the recognition performance of the proposed system.	The evaluation results demonstrate that our method can achieve more than 90% in location-independent human activity recognition accuracy. More importantly, it can adapt well to the data samples with a small number of subcarriers and a low sampling rate.
Ding X, Jiang T, Zhong Y, Wu S, Yang J, Zeng J. 2022.	To adapt the location-independent human activity recognition model well across locations with quite limited samples. To this end, a Channel–Time–Subcarrier Attention Mechanism (CTS-AM) enhanced few-shot learning method that fulfills the feature representation and recognition tasks is proposed.	Extensive experiments show that more than 90% average accuracy for location-independent human activity recognition can be achieved when very few samples are available.	The generalization capability of the model is significantly improved. Extensive experiments show that more than 90% average accuracy for location-independent human activity recognition can be achieved when very few samples are available.

Table 2: Existing research on the inference approaches to facilitate location independence and adaptivity in Smart Homes

Researcher(s)	Overall Aim	Inference Approach/Technique	Solution/Contribution
Morabito, R. and Chiang, M., 2021.	The main goal of this study was to showcase how Machine Learning inference services can be agnostically discovered, provisioned, and orchestrated in a cluster of heterogeneous and distributed edge nodes.	The Machine Learning inference services were exposed over the HTTP interface through the Inference Application API, which in turn encompasses a micro web framework that can trigger the activation and deactivation of specific inference services running on a device through REST API.	The seamless migration between nodes is enabled by transferring specific metadata, including information on the Machine Learning model to be used and the video streaming source.
Liu, W., Zhao, X., Zhao, Z., Ju, Q., Yang, X. and Lu, W., 2021.	To conduct an empirical study on the application of adaptive inference mechanism in various Pretrained Language Models (PLMs), including Generative Pretraining (GPT), GCNN, ALBERT, and TinyBERT.	Pretrained Language Model. Directly loaded the parameters released by Google,1 which was pretrained through the task of mask language model (MLM) and next sentence prediction (NSP). MLM is task for predicting the masked words according to their context.	1) The adaptive inference is extended to other types of PLMs (e.g., GPT, GCNN, and ALBERT). 2) The parameter sharing and adaptive inference are combined to make the PLMs both faster and smaller. 3) The label reduction proposed in this article solves the big label problem in adaptive inference. 4) An easy-to-use toolkit (i.e., FastPLM) is released, which contains many PLMs with adaptive inference capabilities.
Kulkarni, S., Tsyplikhin, A., Krell, M.M. and Moritz, C.A., 2020.	Explored hardware accelerated simulation-based inference over probabilistic models, by combining massively parallelized Approximate Bayesian Computation (ABC) inference algorithm with the cutting-edge AI chip solutions that are uniquely suited for this purpose.	ABC over a probabilistic epidemiology model used to predict the spread of COVID-19.	The ABC algorithm can be significantly accelerated using hardware that is specialized for processing algorithms that can described in a form of computation graph.
Liciotti, D., Bernardini, M., Romeo, L. and Frontoni, E., 2020.	To propose different Deep Learning (DL) models that learn to classify human activities.	The Long Short-Term Memory (LSTM) was applied for modelling spatio-temporal sequences acquired by smart home sensors.	Experimental results performed on the Center for Advanced Studies in Adaptive Systems datasets show that the proposed LSTM-based approaches outperform existing DL and ML methods, giving superior results compared to the existing literature.
Jaberi, M. and Ravanmehr, R., 2022.	Proposed a new approach called HAR-CT to enhance the accuracy of human activity recognition in various classes by adopting a convolutional neural network (CNN). Additionally, an optimization technique using the Ternary Weights Network (TWN) model was also suggested to reduce the complexity of the deep neural network approach that decreases the energy consumption of mobile devices.	The deep neural network is initially designed, developed, and trained, and then this network is compressed to decrease the amount of memory required for information processing. For network compression, the Ternary Weights Network (TWN) is exploited.	The evaluation results of both networks demonstrate that the proposed methods outperform the recently published approaches in human activity recognition.

Martindale, C.F., Christlein, V., Klumpp, P. and Eskofier, B.M., 2021.	Authors proposed a multi-task recurrent neural network architecture that uses inertial sensor data to both segment and recognize activities and cycles. Additionally, to provide a method that is not dependent on feature extraction and a model that is sensor and location independent.	The proposed architecture is a combination of a convolutional neural network (CNN), for detecting edges, and a recurrent neural network (RNN), modelling the temporal dependency of the data. Their approach used CNNs, however combines them with Gated Recurrent Units (GRU), and it focusses on the segmentation of basic activities and their cyclic components.	Their proposed solution outperforms or defines state-of-the-art for HAR and cycle analysis using inertial sensors. They achieved an overall activity F1-score of 92.6% and a phase detection F1-score of 98.2%.
Ngankam, H.K., Pigot, H. and Giroux, S., 2022.	This article presents OntoDomus, an ontology that describes, at several levels, the semantic interactions between ambient assisted living, context awareness, smart home, and Internet of Things, based on multidisciplinarity. The aim of OntoDomus is to provide an interface to collect and analyze smart home data, and then to infer Activities of Daily Living (ALDs) performed to enable decision and action in Ambient Assisted Living (AAL).	The OntoDomus ontology uses domain ontologies to implement the AAL feedback loop. It offers five important aspects of ambient assistance, as follows:(1) usage scenarios that produce user actions; (2) data captured by sensors; (3) system analysis of sensor data; (4) generation of cues to accompany the usage scenario; and (5) evaluation of user response and impact of notifications on usage scenarios. OntoDomus combines SPARQL queries and OWL 2 models to improve the reusability of domain terminology, allowing stakeholders to represent their knowledge in different collaborative and adaptive situations. Furthermore, Jena reasoner was used as an inference engine at each iteration to reason on the semantic model.	It revolves around two main notions: multidisciplinarity, based on specific sub-ontologies and the ambient feedback loop. The implementation of the ambient assistance feedback loop allows communication with sensor and actuator services, to express an ongoing state of an activity performed in a smart home. Unlike the ontologies previously presented, which directs their knowledge on a specific domain, their global modeling of knowledge between the entities of the system makes it possible to better choose, by inference, the concepts and the relations that must intervene to offer quality assistance to ADLs.
Chen, Z., Lu, J. and Wang, R., 2020.	Proposed a novel algorithm based on node weight for relationship inference, which named Relationship Inference By Weight (RIBW). This approach can utilize mobility information from Online Social Network (OSN) effectively. Via treating these data as a whole input, this approach smartly uses the random walk to obtain the random traces on the user-location bipartite graph.	The proposed inference method used SkipGram neural network model to embed the graph.	A holistic relationship mining algorithm based on node weight is proposed. The advantages of this algorithm can be effectively applied to scenarios with high accuracy requirements for relationship inference. The node PR value is used to constrain the random walk range in the selection of the first step random walk link, which effectively solves the problem of graph embedding based on the current situation.

Table 3: Existing Research on context-awareness approaches to facilitate location independence and adaptivity in Smart Homes

Researcher(s)	Overall Aim	Context-Awareness Technique	Solution/Contribution
Iqbal, M.W., Ch, N.A., Shahzad, S.K., Naqvi, M.R., Khan, B.A. and Ali, Z., 2021.	This paper presents ontology based context model using OWL for adaptive mobile devices. It models the context over its four major elements including device, user, environment (location and time) and activity.	The researchers have used the ontological modeling and knowledge representation techniques for the formal modeling of various domain and application concepts for better information retrieval, visualization, analysis and interaction design. Semantic querying (SPARQL) was used for knowledge acquisition. Moreover, the Pellet and HermiT Reasoner were used to verify the rules, relations and constraints to avoid the inconsistency between classes.	Scalability and growth with learning new context in to the shared context knowledge.
Ai, D., Zuo, H., Huang, J. and Yang, J., 2021.	Aiming at the needs of information recommendation in (Online to Offline (O2O) applications, a user context semantic acquisition system based on multidimensional tags is proposed.	The implementation process of this system is as follows: firstly, the user's perception of the current situation is obtained through the multidimensional context tag system; secondly, the context tag is transformed into a formal context concept; finally, according to the predefined context ontology schema, an instantiated user context semantic model is established by using the context concept.	Mobile users are guided to actively share their current situation through social multidimensional tags, so that rich and high-level user context information is obtain by the system. There are three categories of context content in the model 1) User state context: the inherent attributes or characteristics of users. Object state context: the inherent attributes or characteristics of interactive objects. 3) Interaction state context: the scene situation when the user interacts with the object.
Lee, J.W. and Helal, S., 2020.	Building on their prior work to propose a method that analyzes the current state space and determines the present context guided by the collection of generated potential contexts. This paper first introduces modeling of contexts from the collection of state spaces and then addresses reasoning methods.	Three machine learning and statistical methods are utilized. First, two methods of Conditional Probability Table (CPT) and K-means clustering enabled the authors to find k numbers of groups, each of which is declared as a context. Second, Principal Components Analysis (PCA) is used to find important and representative sensors per each context, which finally defines the complete context model. Once the context models are built, one context will be discovered by comparing the current state space and all the context models.	PCA is found to reduce the computational complexity of our method by filtering out sensors which are not contributing or minimally contributing to the context
Lu, C.H., 2020.	Proposes a Context-aware service provision infrastructure along with an agentized and reconfigurable design to improve system adaptability and extensibility.	The activity inference in Algorithm 1 can be invoked by MEBs, and it in turn executes the activity_inference() method, which is a Bayes filter as presented in (12). A generative model using a Bayesian Networks, a discriminative model using multiple-instance support vector machine(MI-SVM) and common baseline model using a decision tree.	This design reduces the overhead from integrating and adapting multiple contextual models in response to inevitable uncertainties in a dynamically changing IoT-enabled smart home environment. The CaSP infrastructure can facilitate multilevel rather than single-level information reuse via message queues residing in the middleware.

Ma, P., Gao, Q. and Fan, J., 2020.	Based on the matrix factorization model, this paper proposes a new interaction mode network model, which consists of three modules: context user / item interaction module, attention mechanism module and context environment overall role module.	They use bilinear function to establish the interaction between context and user / item, and add attention mechanism to distinguish the importance of different context information. Additonally, they add user score bias and item score bias which are changed by context environment to the traditional matrix factorization method. A matrix factorization recommendation model based on context aware feature interaction, named "feature interactive network model" (FINM)	Authors claim that the "Algorithm proposed in this paper is superior to the general recommendation algorithm." They built a context aware feature interaction model, which consists of three modules: context user / object interaction module, attention mechanism module and context] environment overall role module. Among them, the context user / item interaction module mainly realizes the context user /item interaction through different interaction ways; the attention mechanism module can distinguish the impact of different context information on the user / item; the context overall function module can get the effect result of the overall context environment on the user / item.
Leng, Y. and Yu, L., 2021.	In this paper, we divide them into two hierarchies: session-context at the macro-level and event-context at the micro-level, and then propose a Hierarchical Context-aware Recurrent Network (HiCAR) by incorporating both users' micro-interaction with the item and the two-hierarchy contexts, wherein a Session Context Learning module with the n-way hybrid strategy is adopted to model multi-feature interactions in the session-context.	Hierarchical Context-aware Recurrent Network (HiCAR), which incorporates both the session-context and event-context for a more accurate session-based recommendation. The Event-Context Learning (ECL) is designed to capture current purchase intention from the sequential behaviors in the session, which is an improved Recurrent Neural Network to simultaneously model the behavior sequence and its corresponding event-context.	HiCAR model, which divides contexts into two hierarchies namely, the session context and event context, outperforms state-of-the-art baselines on both datasets, which demonstrates its advantages in modeling users' sequential behaviors and contexts simultaneously. The authors contend that "modeling them (two context hierarchies) separately can lead to more accurate recommendations."
Seghier, N.B. and Kazar, O., 2021.	This study presents a new mobile agent-based paradigm for context-aware service discovery. The goal of this study is to improve the WS discovery process by using an ontology-based context model to establish formal contextual descriptors for both service consumers and Web services.	Ontology-based context model. Their approach is founded on the semantic interaction of four distinct agents: Service Agent, Advertiser Agent, Request Agent, Discovery Agent. Their "context-aware matchmaker performs service discovery via semantic matching and selection based on QoS score based on the above (A procedure for matching a query and a service is known as service discovery) contextual description of query and service.	They characterize the concept 'context' in two ways: one from the perspective of service requesters, such as devices, locations, preferences, and activities; and the other from the perspective of Web services, like protocols for service binding, networks, devices and platforms for service execution, and so on.
Rocha, A.P., Almeida, N., Ketsmur, M. and Teixeira, A., 2020.	With the aim of enhancing smart home accessibility, Authors propose a solution for adapting the information presented during interaction with the home to the user's characteristics, capabilities and preferences, as well as to the context, namely the environment's noise and luminosity, and user distance.	Their work advances the AM4I framework, by adding support to interaction adaptation: multiple interaction modalities compliant with the W3C standards, including output modalities, which adapt themselves to both the user and context; implicit/passive modalities, as well as user and context models, which enable user and context awareness.	Authors propose adaptive multimodal interaction for enhancing the accessibility of smart homes. By providing multiple redundant modalities, including output modalities that adapt themselves to both the user and context, everyone from children to older adults can interact with a smart home in any context.
Debruyne, C., 2020.	Authors postulate that solving this problem requires two steps: formalizing context and using that context for building context-aware agents.	GDPR is thus the context and meant we had to conceptualize and formalize (i.e., create an ontology) for the following concepts: "data processing purpose", the "policy" which lists these purposes, and "consent" instances.	Debruyne proposed the formalization of context into ontologies and building of agents that use these ontologies to make them context-aware. Ideally, those agents are- to the extent possible—written in terms of semantic technologies." Thus Authors claim that "In this paper, we integrated both into the narrative for context-aware data integration."

Chen, J., Chen, Z., Zheng, L. and Chen, X., 2022.	It is necessary to capture user preferences based on their historical behavior data.	Temporal knowledge graph is first proposed to support the acquisition of user-perceived environmental data and user behavior data. Next, a user-oriented smart home service prediction model is designed based on the temporal knowledge graph, which can predict the service status and automatically perform the corresponding service for each user.	A spatio-temporal data-driven smart home service control method is proposed, which can learn preference from users' historical behavior data, build a personalized model to predict users' operation, and use a runtime knowledge graph to automatically execute service operations for users. The experimental results show that the proposed method can provide personalized smart home services and well satisfy user demands.

Table 1 presented a summary of the existing research on deep learning and machine learning approaches for location-based personalized home configurations. At a high level, the existing researches conducted between the year 2019 to 2022 as presented in Table 1 demonstrate a serious need for location-independent approach in HAR and/or AAL as great strides have been made towards this end. In particular, [Schmid et al., 2019] proposed a throughput prediction method that could be applied to new regions without the prerequisite of conducting an extensive measurement of campaign in advance. This is a progressive move considering the heterogeneity of ICT infrastructure, configurations, and system components amongst others. However, this study fell short in devoting efforts towards data inference in its approach and only focused on prediction. [Ding et al., 2020] proposed a network-based method as a prototype for HAR using limited data samples. However, the limited data samples, which could be historical data in some contexts, is tantamount to relegating user behavior and preferences to no value in smart home domain. Thus, [Ding et al., 2021] sought to address the limited data challenge and embarked on what they termed massive data collection. However, as stated by the authors, "the limitation of this work is that the activities of different users with diverse habits in different environments and locations have not been included and investigated." Thus, the problem of location-independent user behavior inference remains untested through their solution. Another work by [Ding et al., 2020] focused on location-independent HAR system focused on the activity recognition element in an accurate manner achieving above 90%. However, also this work did not attempt to address the inference of ADLs in its location-independence approach. Similarly, [Ding et al., 2021] made a profound contribution for location-independent HAR task with a model that is capable of learning the characteristics of activities in different locations. However, the study was limited at learning new contexts, not just activities, and infer user context to achieve system composition and user adaptation based on historic data. Furthermore, [Ding et al., 2022] proposed an adaptive location-independent human activity recognition model for implementation across locations with quite limited samples. Again, successful at its own mission, but did not address the need to infer historical data generated from a previous locations and activities.

Table 2 presented a summary of existing research on inference approaches to facilitate location independence and adaptivity in Smart Homes. At a high level, existing research between the year 2020 to 2022 heavily relied on artificial intelligence techniques and only a few relied on probabilistic models to infer ADLs on IoT systems. In particular, [Morabito and Chiang 2021] showcased how Machine Learning inference services can be agnostically discovered, provisioned, and orchestrated in a cluster of heterogeneous and distributed edge nodes. This enabled the provision of seamless migration between nodes enabled by transferring specific metadata, including information on the Machine Learning model to be used and the video streaming source. However, their proposed system is deployed to each edge device and this could prove cumbersome and may not scale well in a device proliferated and heterogenous smart home domain. [Liu et al., 2021] conducted an empirical study on the application of adaptive inference mechanism in various Pretrained Language Models (PLMs), including Generative Pretraining (GPT), GCNN, ALBERT, and TinyBERT. Considering the heterogeneity of devices in the smart home domain and unannotated data generated by these devices or even limited annotated data in some instances, designing specialized models for specific tasks would not scale well. PLMs could provide for the necessary capabilities in representation learning for context-aware models. [Kulkarni et al., 2020] explored hardware accelerated simulation-based inference over probabilistic models, by combining massively parallelized Approximate Bayesian Computation (ABC) inference algorithm with the cutting-edge AI chip solutions that are uniquely suited for this purpose. Speeding up inference process especially of a deep learning model and providing the necessary supporting infrastructure is indeed critical to reduce overall system/application latency and ensure seamless user experience. It remains to be seen how ADLs inference in newly encountered IoT systems/applications would would be supported during user mobility. [Liciotti et al., 2020] proposed different Deep Learning (DL) models that learn to classify human activities. The Long Short-Term Memory (LSTM) was applied for modelling spatio-temporal sequences acquired by smart home sensors. The study affirms the potency and relevancy of DL approaches based on LSTM as viable solutions to improve significantly the ADL recognition task in the smart home domain. It further sets DL (LSTM) techniques apart from the traditional ML techniques such HMM, CRF, etc. whom other studies have relied on in the past. The Bi-LSTM exploits all available input information in the past and future of a specific time frame. However, the study did not go as far as inference of ADLs into newly discovered smart homes systems/devices but only focused on DL techniques performance on ADL recognition tasks. [Jaberi and Ravanmehr 2022] proposed a new approach called HAR-CT to enhance the accuracy of human activity

recognition in various classes by adopting a convolutional neural network (CNN) and an optimization technique using the Ternary Weights Network (TWN) model to reduce the complexity of the deep neural network approach that decreases the energy consumption of mobile devices. This is another study that proved the potency of a hybrid deep neural network using CNN and LSTM, which improves the accuracy of the predictions, and then applying the ternary weights and activations to the results. [Martindale et al., 2021] proposed a multi-task RNN architecture that uses inertial sensor data to both segment and recognize activities and cycles. Additionally, they proposed a method that is not dependent on feature extraction and a model that is sensor and location independent. Notwithstanding the fact that GRUs also avoid the vanishing gradient problem associated with RNNs, similarly to LSTM, favoring the LSTM than GRU improve performance for the latter has fewer trainable parameters than the former. [Ngankam et al., 2022] proposed OntoDomus, an ontology that describes, at several levels, the semantic interactions between ambient assisted living, context awareness, smart home, and Internet of Things, based on multidisciplinarity to provide an interface to collect and analyze smart home data, and to infer ALDs performed to enable decision and action in AAL. Theirs is a typical ontological modelling approach, well grounded in context-awareness theories and practices. However, key weaknesses of their approach are; firstly, one the lack of learning capabilities even though the article concedes that "Knowing how to adapt to changing circumstances and react according to the context of use requires the use of artificial intelligence analysis techniques, as shown in step 3." Secondly, the solution is based on a single home experimentation and remains untested for user mobility purposes. Thirdly, OntDomus has also indifferently relied on properties such as the physical location, the isLocatedAt (main_bed, main_bedroom). Fourthly, OntoDomus had no database, all information is structured in the ontology and thus makes no room for historical personal data (large previous datasets) inference in determining user "assistance" for (AAL). [Chen et al., 2022] proposed a novel algorithm based on node weight for relationship inference, which named Relationship Inference By Weight (RIBW). Their approach can utilize mobility information from OSN effectively. Through treating this data as a whole input, this approach smartly uses the random walk to obtain the random traces on the user-location bipartite graph. The proposed Relationship Inference Algorithm based on node weight proved good for its purpose, particularly when it comes to combining location data and mobility data. However, the algorithm requires explicit knowledge of the location to predict relationship of users and lacks learning capabilities necessary for data inference in different locations.

Table 3 presented a summary of existing research on context-awareness approaches to facilitate location independence and adaptivity in Smart Homes. Similarly, studies on location-independence and inference techniques conducted between 2020-2021 shows that location data is heavily relied upon for service characterization more especially for ontological modelling. In particular, [Iqbal et al., 2021] presented an ontology-based context model using OWL for adaptive mobile devices. It models the context over its four major elements including device, user, environment (location and time) and activity. Although in their model, context is dynamically extracted from the environment, this is done to "identify the situation of the user at a certain time or location." [Ai et al., 2021] proposed a user context semantic acquisition system based on multidimensional tags aiming at the needs of information recommendation in Online to Offline (O2O) applications. In their approach, location data remains critical to determine the interacting object(s) and infer user's "historical interaction context". In a wide domain such as restaurants, it may be scalable to predefine and encode likely locations and objects and thus their solution may still scale. Heterogeneity and idiosyncrasy in smart homes domain may render this solution impractical. Additionally, the solution lacks a proper algorithm capable of learning and discern new environments in real-time. [Lee and Helal 2020], building on their prior work, proposed a method that analyzes the current state space and determines the present context guided by the collection of generated potential contexts. Their approach first introduces modeling of contexts from the collection of state spaces and then addresses reasoning methods. The proposed future work by the authors to examine unsupervised learning methods and assess their success in recognizing present contexts without training for real-world applications where training may not be possible renders their solution limited for implementation in real-world applications. [Lu 2020] proposed a context-aware service provision infrastructure along with an agentized and reconfigurable design to improve system adaptability and extensibility. Lu's solution depends on service feedbacks to realize human-system interactions for online adaptation and thus lack machine automation. [Ma 2020], based on the matrix factorization model, proposed a new interaction mode network model, which consists of three modules, namely the context user / item interaction module, attention mechanism module and context environment overall role module. This study is premised on its conviction that "user's preferences often change with the change of context environment, which has subtle but powerful influence in the process of users' selection of items" and thus introduced an "attention mechanism to distinguish the influence of different context feature information on the user/item" through a matrix factorization recommendation model. Matrix factorization, which are good to model general interests, but are touted to be

"missing the sequential features which contains users' preference shift through time" [Leng and Yu, 2021]. Deep Learning methods especially RNN have proven to be more effective in modeling sequential behavior patterns [(Leng and Yu, 2021]. However, the attention mechanism can be adopted in a deep learning approach, to consider the users' current interests from the short-term memory of the last inputs. [Leng and Yu 2021] proposed a Hierarchical Context-aware Recurrent Network (HiCAR) by incorporating both users' micro-interaction with the item and the two-hierarchy contexts, wherein a Session Context Learning module with the n-way hybrid strategy is adopted to model multi-feature interactions in the session-context. The context modelled in the session layer considers the "environment in which each session occurs, i.e. session-context, which indicates session occurred in location l at time t and weather w." Due to user mobility needs which renders the environment dynamic and unpredictable, it remains to be seen if a session can be based on the interaction of a user and system, independent of location. [Seghier and Kazar 2021] presented a new mobile agent-based paradigm for context-aware service discovery. The goal of their study is to improve the WS discovery process by using an ontology-based context model to establish formal contextual descriptors for both service consumers and Web services. Similarly, to the many similar solutions, the proposed Ontology-based context model heavily relies on spatial data (location in particular) in its service discovery approach. [Rocha et al., 2020], with the aim of enhancing smart home accessibility, proposed a solution for adapting the information presented during interaction with the home to the user's characteristics, capabilities and preferences, as well as to the context, namely the environment's noise and luminosity, and user distance. The study focused on facilitating smart systems to adapt to different user contexts and general contexts in a specific smart home (inside a home). By default, their approach was limited in terms of (i) adapting user contexts in a completely different environment and (ii) learning such new environment, discover services and inferring user context appropriately. Generally, the study was limited when it comes to learning capabilities and relied on a completely mapped out smart home topology in which location data is central. [Debruyne 2020] observed that "current models represent the context in crude and simplistic terms." Debruyne added that "these context models are furthermore built for specific tasks or application domains such as query optimization or a smart home." Debruyne's view is that, "the current state of affairs is thus is not fit for intelligent data integration as the State-of-the-Art often limits itself to a limited number of so-called sensors, which are often crude and simplistic." To solve this problem, Debruyne postulated that two steps are required, namely the formalizing context and using that context for building context-aware agents. Additionally, Debruyne argue that even "related work on context-aware data integration is sparse and often in specific and siloed environments such as IoT and Smart Homes." Thus, it remains to be seen if context representation can be free of limitations imposed by location data and rather incorporate other context properties to achieve better data and service integration." Finally, [Chen et al., 2022] argued int their work that it is necessary to capture user preferences based on their historical behavior data. However, their approached used a Temporal Knowledge Graph which also relied on location data to characterize services that should be automatically provided to the user based on user behavior in an environment. Where a user is bound to a single home or IoT system, solutions with predefined location data such as a Kitchen, bedroom, lounge, and bathroom amongst others, where smart devices are mapped accordingly, are practical and effective. However, existing research approaches remain shortsighted on the context-awareness realities presented by user mobility where a user should seamlessly adapt to newly discovered smart-homes or IoT systems.

5. Findings and Discussion

As presented in the review of selected papers section of this paper, research has been conducted towards establishing appropriate techniques that could be employed to infer Activities of Daily Living (ADL) over heterogeneous pervasive intelligent environments to facilitate user mobility without making extensive use of location context. At the least, the following issues and challenges are deduced as part of the findings of this systematic review:

(1) Existing solutions towards facilitating user-mobility in smart homes remain limited to a single specific home or within a particular IoT system.
(2) Many interventions were shortsighted to anticipate the need for personalized home configurations to support user mobility in the smart-homes domain.
(3) Lack of capabilities to infer historical data in smart systems to achieve full context-awareness and user adaptivity.
(4) Both ontological modelling and learning approaches deeply rely on location data in determining context.

The computing processes in the smart-homes domain require dynamic location, adaptability, and automatic configuration of the smart home environment on timeous basis. This is resultant of the fact that, "agents (human and software) must exchange their knowledge and cooperate together to understand a local context and reach their goals" [Roussey et al., 2011]. Notwithstanding the traditional agents' intra-relationship focus on knowledge exchange and corporation in the smart-homes domain, the modern-day agents, particularly humans, are on the move and bound to traverse between systems. An inter-relationship focus in the smart-homes domain is ideal for continued knowledge exchange and cooperation between agents, inferring input historical data into devices and sensors of the newly discovered smart home systems. In the inter-relationship focused smart-homes domain, historical data is of paramount importance to ensure user convenience and seamless computing. Several researches did not really utilize the historical data for context reasoning but only utilized the situational information from heterogeneous sources such as the web, corporate databases, etc. as explained by [Roussey et al., 2011]. They define situational information to mean data about the person, schedule, time, technical characteristics of the devices installed in the room. Using the situational information, the system deduces the role and intensions of the user by reasoning with the context, explains Roussey. The issue with the situational information, as implemented in COBRA ontology is that, albeit supporting pervasive context-aware systems in a smart space environment, it exploits both default and abductive reasoning for context reasoning [Chen et al., 2003] which both lack a sense of learning user behavior with time progression. Research work incorporating a learning capability for collection and analysis of the "situational information" to form historical data, that will be used as user's input in future discoveries of smart homes and thus foster user adaptation and enable continuity in user experience, is evidently outstanding.

According to [Oppermann 1994], a system is adaptable if the whole adaptation process which includes the initiation, proposal, selection and production of adaptation, is controlled by the user itself. Additionally, [Zipf and Jost 2006] advocated, "systems are adaptive if these adaptations are done automatically without the direct involvement of the user." [Logota et al., 2015] support this position in their definition of context-aware devices and programs that are alive and capable of intelligent behaviors. This service would enable networks and services to deduce only relevant context-information as a necessary act to enable them to dynamically adapt their behavior in dynamic environments, added Logota et al. The ability of systems to self-adapt or provision of services based on network context information was also emphasized by [Ocampo et al., 2006]. This requirement is ideal for smart-homes systems to self-adapt or provide services based on user situational information, the historical data, which discriminates against the location context in the adaptation process. This is critical for smart-home domain characterized by unprecedented networked entities whose location context may differ from one system to another. Aptly articulated by [Sousa and Garlan 2002] "resource variability arises naturally in a ubiquitous computing setting through user mobility (a user moves from one computing environment to another), and through the need to exploit time-varying resources in a given environment (such as wireless bandwidth)." Based on this practicality, it is necessary for smart-home systems to generate and exploit contextual data describing users and their preferences independent of the location context. This requirement could benefit smart-home domains in adapting user behavior upon presence detection.

The continued lack of capabilities to infer historical data in smart systems towards achieving full context-awareness and adaptivity is a cause for concern in this era machine automation. Against the promises of ubiquitous computing, which Sousa and Garlan summarized two decades ago to the extent that "a ubiquitous computing infrastructure would allow users to move their computational tasks easily from one environment to another." They added that "moreover, users should be able to take full advantage of the local capabilities and resources within a given environment, even as other users and devices enter and leave that environment, and as resources (like available bandwidth) change." Research work towards this noble goal seem to be legging behind as efforts are limited within a single home or within a particular IoT system. Research could now advance towards inferring user-behavior into heterogenous computing devices and systems as the user moves from one environment to another. Such research initiatives could investigate infusing deep learning and machine learning techniques such as RNNs to efficiently determine context in different locations/environments visited by the user without seeking to impose uniformity on the environment. The benefit of this kind of research work could save the user from a rigorous manual system registration and composition process and help deliver on the promises of ubiquitous computing.

6. Conclusion

Literature review shows that the promises of ubiquitous computing to enable user mobility across heterogenous devices and systems is yet to be fully realized. At the most, findings show that, advances to facilitate user mobility within a single home or within a particular IoT system have been made with greater success. To this end, various mechanisms such as ontological modelling, probabilistic models, learning models as well as architectural frameworks amongst others have been introduced mainly to achieve context-awareness needs. However, literature review also shows that, there still exists a research gap around issues of user-behavior inference across heterogenous devices and systems to better facilitate context-awareness during system composition and user adaptivity in the smart homes domain. Based on literature review, it was evident that the major computational challenge behind this setback is deep-rooted in the over-reliance on location data in determining context by existing solutions. We conclude that research efforts to overcome this challenge should be devoted urgently, exploiting the capabilities of deep learning algorithms and data analytics even further.

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Conflict of interest

The authors have no conflicts of interest to declare.

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Authors Profile

Phumzile Nomnga, is a Lecturer in the Department of Computer Science at the University of Fort Hare and is concurrently pursuing a PhD in the same institution. His research focus encompasses several areas, notably the Internet of Things (IoT), Artificial Intelligence (AI), Mobile Networks, and Big Data Analytics.

Prof. K Sibanda is a well-experienced Walter Sisulu University academic, whose research interests are in Artificial Intelligence with a bias to machine learning. He is a member of the Artificial Intelligence for development Africa. In his career, he has supervised to completion 5 PhD and 19 MSc in Computer Science students. Most of his research revolves around machine learning techniques for classification, clustering and prediction. He has begun exploring such techniques for educational solutions. He believes that machine learning approaches are very robust in answering a wide range of problems including teaching and learning problems.