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# A Context-Aware Pain Trajectory Framework for Low Back Pain Management

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## *Abstract*

*Current advances in mobile and sensor technologies have provided new opportunities for many fields of research, especially in healthcare. Chronic pain is one such field, where low back pain is a common problem that affects 20% of the population, and is also a major contributor to disability. Unfortunately, not much is yet known about the contributing factors, nor the nature of low back pain itself. Existing research does not collect data frequently - with most studies only collecting pain data monthly, or half yearly. Experts agree that there is a need for the increase in frequency of data collection, and to study the context of the patient's pain experience in order to understand the nature of pain. Currently, there are not any research that attempts to include the context around the patient's pain experience, to collect and analyze data for correlations on an individual patient basis. This research will propose a context-aware pain trajectory approach capitalizing on the opportunities that arise from advances in mobile and sensor technologies, to increase the frequency of data collection, and enable the collection and integration of the patient's context into current low back pain models using day to day pain trajectories.*

*Keywords: Low Back Pain, Context Awareness, Context Model, Pain Trajectory*

# 1 Research Topic

Low back pain is the leading chronic pain condition, and an important cause of disability worldwide (Driscoll et al., 2014). In Australia, an estimated 20% of the population suffer from persistent pain, which is estimated to cost $34 billion yearly, when taking into consideration lost workdays, health-care and other associated costs (Pain Management Research Institute, The University of Sydney, 2014). Chronic pain is defined as pain lasting more than 3 months (Merskey, 1986). There has been enormous growth in this field over the last decade, with 57% of existing research being published over this period of time (Elsevier, 2014). Studies have used a large variety of approaches in their attempt to study the nature, the causes and factors that contribute towards low back pain. These studies typically use a pain trajectory to represent pain intensity over time, and it has been shown to have some limitations. The current use of the pain trajectory does not allow for the understanding of the context around the changes in pain, and research shows that the study of the context, or factors of low back pain could increase the depth of analysis and understanding provided by the data. Unfortunately, current studies typically attempt to study entire populations without taking into consideration the context available (Cook, 2003; Dunn, Jordan, and Croft, 2006; Dunn et al., 2011; Stanford et al., 2008). Olson's work suggests that pain has an individualistic nature, and thus no two patients will have the same pain experience (Olson, 2014). Therefore, it is important to be able to understand the context around the patient's pain experience, and to be able to capture that contextual data. There currently are no existing approaches that provide the capability to do so in a unifying manner that utilizes recent advances in technology.

This research addresses some issues in data collection that are seen in low back pain studies, which includes the cost, accuracy and contextual usefulness towards understanding the nature of pain. It will do so by utilizing the benefits from advances in technology to increase the frequency of data collection, and provide the capability to collect data about the context of a patient's pain, and display it in a meaningful manner. This research is expected to contribute towards the understanding of the nature and context factors of low back pain for longitudinal studies in pain management.

Based on a review of existing literature, some gaps have been identified, which leads to two main research questions outlined in the following section.

# 2 Research Question and Aims

The two main research questions (RQ) are:

**RQ1** - How can we provide an approach to enable higher frequency and richer sources of data collection for low back pain trajectories?

**RQ2** - How to integrate the patient's context into current low back pain models?

As a sub-question to the second research question:

**RQ2.1** - What is the impact of the context-aware pain trajectory approach on low back pain studies?

In answering these questions, this research aims to design and develop a framework that uses a Context-aware Pain Trajectory (CaPT) approach in incorporating richer sources of data, and support higher frequency of data collection for day-to-day low back pain trajectories. As part of answering the second RQ, this research will design and develop a context model to represent information from diverse sources such as sensors, APIs, social media, medical records and questionnaires about the patient's context in a unified, consistent manner for low back pain. Finally, a prototype of selected components of the framework will be implemented to validate the proposed context model and context-aware pain trajectory approach by conducting comprehensive evaluation, using simulations with secondary data in collaboration with domain experts, to assess the impact of the approach on low back pain studies.

In this research, low back pain provides the context to the project, but the design of the approach and model can be generalized to other chronic pain management fields and conditions.

The following section will provide an overview of the theoretical foundation from the existing research literature.

# 3 Theoretical Foundation

## 3.1 Longitudinal Studies of Low Back Pain

As outlined previously, chronic pain is an incredibly expensive and relatively widespread problem throughout the world. In Australia, an estimated 36.5 million work days each year is attributed towards chronic pain (Pain Management Research Institute, The University of Sydney, 2014), and in the United States, a 2012 review reported that it costs between $560 to $635 billion annually, and although these costs were conservatively estimated, it had already exceeded the economical costs of the 6 most costly major diagnoses, which includes cardiovascular diseases, injury and poisoning (Gaskin and Richard, 2012).
Low back pain is the second most commonly reported problem within the area of chronic pain at 29.4% (Henderson et al., 2013), and such studies typically are longitudinal studies due to their nature of monitoring a population of individuals over an extended period of time and collecting repeated measures of data. The cost associated with collecting data for such studies tends to be high due to the amount of data collection points required. Recent studies have begun adopting the use of technology in collecting data, both to increase the collection capabilities and reduce the overall cost of collecting useful data (Hendrick et al., 2009; Lall et al., 2012). It is seen that unlike other fields of similar studies, the rate of adoption of technology is relatively slow, and most studies typically collect data on an in-frequent basis.
The study of low back pain is a rapidly growing interdisciplinary field that is still being developed (Windt and Dunn, 2013), as much is not known about the specific nature of low back pain, and how it is affected by other characteristics such as clinical and demographics (Macedo et al., 2014). These approaches include investigation into causes and treatments for specific pain, and clinical trials on drugs that can block or ease pain. Furthermore, there are studies that focus on identifying factors that can affect pain, along with research towards understanding the nature of pain itself, which is made difficult by the fact that clinical pain is subjective in nature (Abu-Saad and Holzemer, 1981; McGuire, 1984), as it is a self-reported measure by the patient (Malhotra and Mackey, 2012), and is difficult to measure objectively and accurately (Loder and Burch, 2012).

### 3.1.1 Data Analysis

It has been observed that the data analysis techniques used in this field primarily consist of statistical analysis, with the literature suggesting that the most common analytical model being the latent class model. The latent class model is used to discover causal relationships between the factors and low back pain, it allows for pain profiles across multiple pain sites to be identified, and also provides the capability to categorize patients into generic classes based on their overall pain trajectory.
The pain trajectory is the visualization of the pattern or progress of pain intensity, and is represented as a two dimensional graph plotting pain intensity over time intervals (Chapman et al., 2011). It has been validated as being precise enough to classify patterns of reported pain in a reliable manner for patients (Chapman et al., 2011). Studies have used a variety of methods in trying to generically classify patients based on their overall pain trajectory, for example, clusters labeled as 'persistent mild', 'recovering', 'severe-chronic' and 'fluctuating' (Dunn, Jordan, and Croft, 2006).
Existing analysis approaches using statistics alone are not able to provide an understanding of low back pain. They are excellent for identifying characteristics as well as the significance of factors, which studies have used in characterizing populations of patients' pain trajectories. However this does not address the problem of pain having an individualistic nature (Olson, 2014). The statistical models are not able to analyze the context of the patient's pain experience. Therefore, it can be seen that there is a need to study the patient's pain experience in multiple factors. There currently does not exist research that attempts to

examine as many of these factors as possible. Existing research is focused on intervention studies for management of pain from a multidisciplinary perspective, or on models for a specific factor.

### 3.1.2 Data Collection

With regards to the data collection techniques, the most commonly used instruments are questionnaires. Recently, there has been a slow move towards the adoption of newer instruments for the collection of data, which includes diaries, and sensors (McGorry et al., 2000; Weering, Vollenbroek-Hutten, and Hermens, 2012). The collection modes for data are most commonly done in-person, via mail or over the telephone. There were few studies that utilized mobile SMS technology (Macedo et al., 2014), and lesser that utilized the Internet for collecting data from participants.

As mentioned previously, a problem with the frequency of the data collection intervals are that most studies collect data in-frequently, with monthly, half yearly, yearly being common intervals. The critical point here is the accuracy of patient recall on their pain experience over an extended period of time, where research shows that there is a small bias that can affect such data (Schneider et al., 2011; Turk and Melzack, 2011). Similarly, research shows that more accurate data is collected using diaries due to the real-time nature of such instruments, versus the reliance on the accuracy of patient memory recall (Turk and Melzack, 2011). There are a large variety of data collected that can be classified into various factors, which includes demographical data, psychological, medical history data, to name a few. There is evidence that shows that collection of data about the entire experience from multiple factors, or context should be carried out, in order to correctly understand the entire experience and nature of pain (O'Sullivan, 2012).

## 3.2 Context Awareness

The concept of context has been around since the 1990s, but only really evolved in the last decade. There are many definitions for context, but we adopt Dey's definition where "any information that can be used to characterize the situation of an entity, where an entity can be a person, place, or physical or computational object" (Dey, 2001, p. 304). Related to the concept of context is contextual awareness, which refers to the ability of a process, system, or program to consider the context by sensing states of its environment and itself, in order to react appropriately (Schilit, Adams, and Want, 1994).

Longitudinal studies in other fields already consider some form of context (Bowen et al., 2008; Cook et al., 2002). The study of context is predominant in fields such as psychology and behavioral sciences, as it provides important information on mechanisms of the phenomena through studying the context to understand the situation (Green et al., 2009; Mishler, 1979). Currently, there are no well developed taxonomies or models that exist to describe situational and contextual factors in relation to humans (Kelley, 2003), especially in the field of low back pain.

In applying lessons from other fields to low back pain, the context around the patient's pain experience can provide valuable information about the situation around the patient's low back pain, which could then lead to a better understanding of the fluctuation and changes in pain.

We define contextual data as data about the context of the phenomena. This research has identified two types of instruments, contextual and traditional. Traditional instruments are classified as such because they provide other data relevant to low back pain studies, but are not necessarily considered contextual information. Four such contextual instruments are sensors, third party data (API), social media and diaries. Similarly, two traditional instruments are pain scales to measure pain, and questionnaires.

The contextual data obtained is modeled using a context model. There are many classes of context models, but the model selected will have to support the contextual data instruments, have the capability for contextual reasoning, the ability to model change over time, and support mobile devices to utilize advances in technology. A comparison of a selection of common context models has produced the Fuzzy Situation Inference model (Haghighi et al., 2008), which this research will extend.

### 3.3 Summary

In summary, research shows that the intensity of pain varies across the course of a single day (Benedetti, 2002), therefore the existing frequency for collecting pain data is insufficient to produce an accurate understanding of the nature of pain. Pain has been said to be individualistic (Olson, 2014), thus the analysis should be done on an individual basis as the patients' pain experiences can vary with the context of their lifestyle and people around them (De Souza and Oliver Frank, 2011). While there currently are research studying contributing factors, there are no works that attempt to study the nature of pain from a wider perspective that includes contextual factors. Finally, there is a need to capitalize on the potential of using advances in technologies to enable higher frequency of data capture of patient pain context and changes in the patients' pain intensity.

The following section will highlight the research methodology and evaluation planned.

## 4 Proposed Research Methodology and Evaluation

The focus of this research is the design and development of the approach consisting of the framework which will provide the capabilities outlined in the research aims, as well as the context model. Therefore it will follow the Design Science methodology outlined by Hevner et al. (2004) and Peffers et al. (2007). Design science can be briefly described as a methodology that is concerned with producing an artifact that will achieve the goal.

The research development process will follow Peffers et al. (2007)'s DSRM Process Model, which outlines an iterative process shown in Figure 8 that starts by identifying the problem, defining objectives, design and development of an artifact, demonstration of suitable context to solve a problem, evaluating the artifact, iterating back to design and development and communicating the result.

This research will produce three deliverables, which are the context model to be included in the framework, the CaPT framework itself, and an implementation of part of the framework's components, which will be evaluated for efficiency and usability, as well as usefulness to domain experts.

There is a simulation planned, pending ethics approval which will consist of increasing the data collection frequency of an existing clinical trial, and adding real-time processing capabilities to the online data collection system that I built in 2013. There is a twofold importance here, first which is the ability to track participants in real-time, and to determine if the higher frequency of data collection will improve data analysis capabilities; The second being the demonstration that usage of such tools enables richer data collection without increased cost to researchers.

The final evaluation of this research will consist of simulations using real world secondary data resulting from a real world clinical trial that is in progress at Cabrini Health. There are a series of domain expert interviews planned to evaluate both the model and framework. This simulation will be conducted on the instantiation of some components of the framework as an Android Application.

## 5 Current Stage of Research

This research is currently in the design phase of the framework. The framework and models are being refined with collaboration from domain experts. As mentioned previously, this research proposes a context-aware approach to low back pain management using pain trajectories. This approach consists of two main parts, which are the Context-aware Pain Trajectory framework (CaPT), and the context model. The literature review on the existing research is almost complete, which will address part of RQ1 and RQ2. The following sections will provide a brief overview of these two parts, along with the expected contributions from this research.

## 5.1 Context-aware Pain Trajectory (CaPT) Framework

In addressing RQ1, we propose a framework that utilizes novel and rich sources of information around the patient's day to day pain experience, to produce a context-aware pain trajectory. The CaPT framework consists of two sets of components that belong to either the server or client side. The proposed CaPT framework is shown in Figure 1.

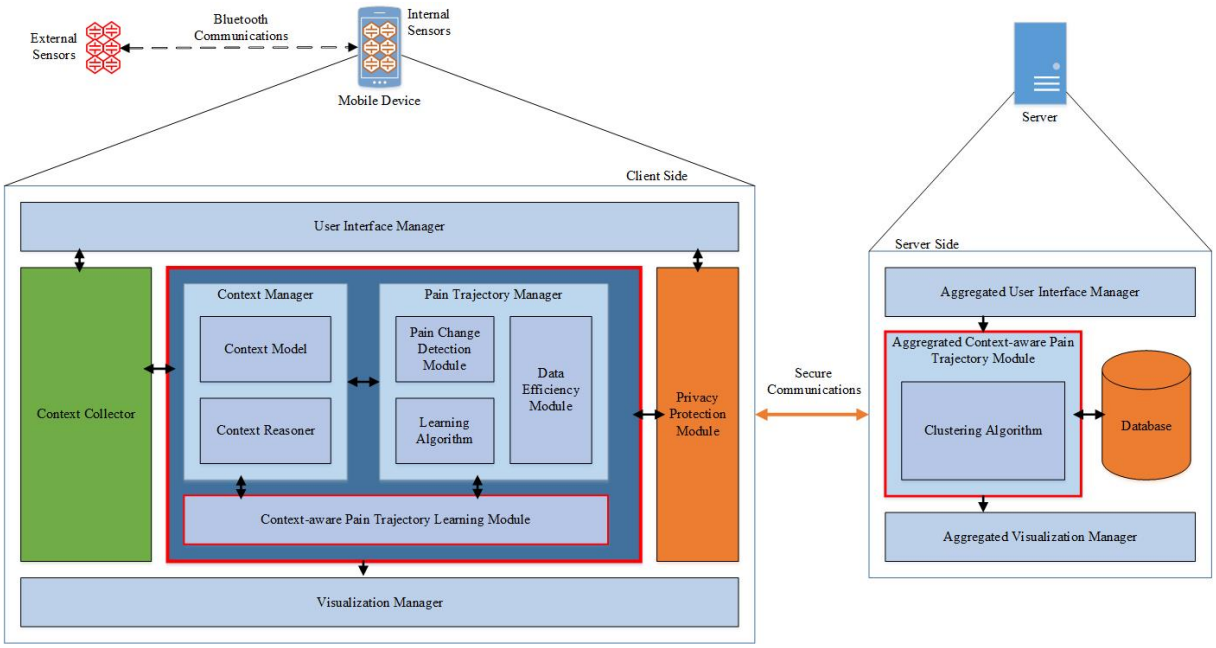


*Figure 1. CaPT Framework*

A brief overview of the components are provided as follows.

The client side contains seven main components. These are the Context Collector, Context Manager, Pain Trajectory Manager, Context-aware Pain Trajectory (CaPT) Learning Module, Visualization Manager, User Interface (UI) Manager, and the Privacy Protection Module. These modules are responsible for collecting input from the client side device, process and tag the data variables collected with their appropriate context factor using the context model, perform contextual reasoning, detect changes in reported pain intensity, and produce graphs which includes pain trajectories with context for the user. The context model will be discussed in the following section. The privacy protection module allows the user to set tags on all data variables collected with preset levels that determine what data is shared with the server.

Similarly, the server side contains four main modules, which are the the Database, the Aggregated CaPT (ACaPT) Module, the Aggregated Visualization Manager (AVM), and the Aggregated User Interface (AUI) Manager. Data is transmitted securely using private / public key encryption from the mobile devices to the server, and only public or shared data is sent. The data is tagged internally with a unique user ID for research and internal referencing purposes. The server modules have access to all data captured from all users who opt-in. The server side components contain the database to store all data generated and received in a secure manner, clustering and learning algorithms for analysis at multiple levels for researchers, as well as visualization routines for generating and displaying results and graphs of data and analysis collected at different custom levels.

## 5.2 Context Model

The context model addresses part of RQ2 by providing a context map of how each variable maps onto the context factors. This research has studied current context models for low back pain, and there have been multiple approaches to designing such models. Two of the main approaches are; i) modeling factors of pain leading to burden, and ii) modeling risk factors of pain. As this research is representing the context of a patient, it then makes sense to extend an approach that models contextual factors to some degree.
Through the literature review conducted, this research has identified ten contextual factors for the context model. These factors identified extend the factors identified in Buchbinder et al. (2011)'s work, and considers additional important context attributes based on the literature review in recent studies (Dunn et al., 2011; Lorenc and Marriott, 2014; McGorry et al., 2000; O'Sullivan, 2012; Paltoglou and Thelwall, 2012; Pang and Lee, 2008; Weering, Vollenbroek-Hutten, and Hermens, 2012). There are ten context factors, which includes Pain, Demographics, Employment, Physical, Disability, Social, Psychological, Medical History, Treatment and Environment. This context model will form part of the context model component within the CaPT framework, to allow the classification and tagging of contextual data collected with their relevant context factors.
The proposed context model is more comprehensive and supports new sources of data such as sensors, APIs and social media. It will help to address items to be supported by the framework, and to some extent, guide the capabilities of the framework previously described.

## 5.3 Expected Contributions

This research project will design and develop a new approach that utilizes novel and rich sources of information about patient's daily pain and pain experience using day to day pain trajectories that takes into consideration the patient's context for low back pain studies of pain management. This project has identified the limitations of the existing data analysis and collection methods, especially in assessing contributing factors of low back pain, as well as the issue of the accuracy brought about by the infrequent collection of pain data. This project has also identified opportunities that exist with utilizing advances in mobile and sensor technology to enhance data collection of contextual information towards an understanding of the patient's pain experience and context around the patient's pain events.
This research aims to contribute towards design and practice by the design of a new approach that enables higher data collection frequencies and the use of richer sources of data for low back pain trajectories. The framework used in the approach will provide the capability to capture contextual information from diverse sources about each pain event from the patient using richer sources of data in both passive and active ways. This research will extend and empirically validate current low back pain context models by considering the patient's context. The model will also be generalizable to other chronic pain management fields.
In contribution to knowledge, the framework and outcomes of this research will provide better insight into the treatment and management of low back pain for domain experts, and provide an opportunity for the patient to better self-manage and understand the nature of their pain, which can lead to lesser problems with over-diagnosis and over-management by doctors, and reduce the cost of unnecessary visits to doctors. This research is also expected to contribute to the body of knowledge in fields such as mobile health-care, fuzzy context reasoning, mobile and ubiquitous computing, and to the low back pain research community.

# 6 Plans for Completion

Currently, this research is focusing on the design and refinement of the proposed model and framework, and the familiarization with the Android development toolkit. The planning and design of the domain expert interview question and simulations are ongoing and expected to run through Nov 2015, with ethics submitted during the later part of this year. Part of this research is in collaboration with colleagues at Cabrini Health. There are publications planned for the IS and medical fields of conferences and journals,

some in collaboration with Cabrini Health. Figure 2 shows the planned research timeline. It is expected that this research will be completed by the first quarter of 2017.

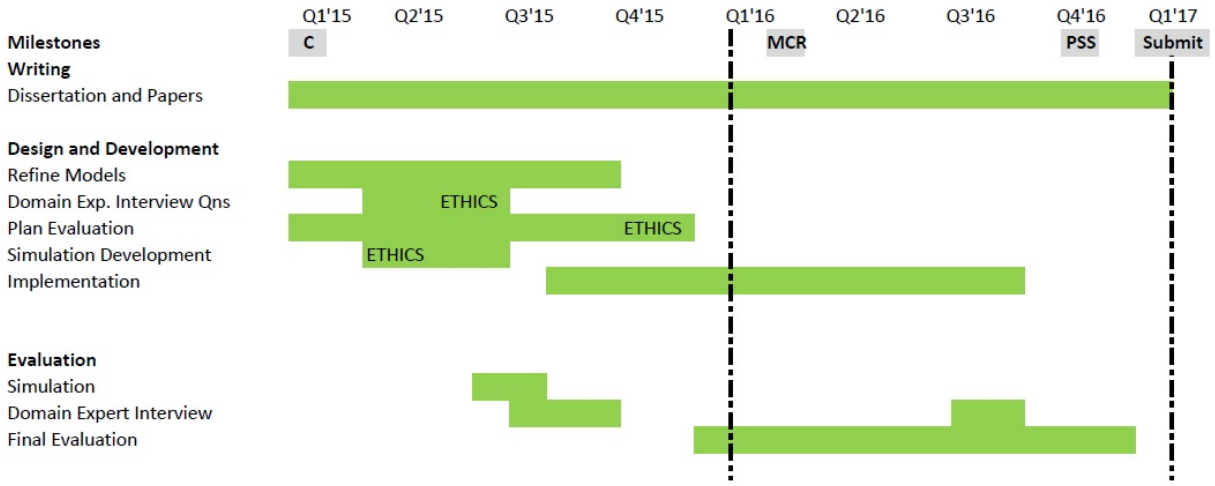


*Figure 2. Research Timeline*

In summary, in answering the research questions laid out previously, the following are planned:

- RQ1: Review of existing literature and models, selection, design and development of a framework that takes into consideration richer sources of data collection that enables higher frequency of data collection for low back pain trajectories. This is included in the literature review and the design of the framework. The framework will be validated using an instantiation over a simulated evaluation with real world secondary data with domain experts.
- RQ2: The review of existing contextual model literature for low back pain, and extension of a selected model using a contextual factor approach. The deliverable is the context model proposed, which will be refined over this year.
- RQ2.1: The impact of the new proposed approach will be evaluated as part of the simulation described previously, with the final evaluation that is planned in collaboration with Cabrini Health and domain experts. The outcome will be addressed in the thesis results and discussion chapter.

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