Chapter 1

Introduction

"The original vision of AI was to understand the principles that support high-level cognitive processing and to use them to construct computational systems with the same breadth of abilities as humans. The cognitive systems paradigm attempts to continue in that spirit by utilizing structured representations and heuristic methods to support complex reasoning and problem solving".

Pat Langley

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1.1 Background

How would you respond if asked,"*Have you ever tried the task of moving from A to B* ?". What will be your answer? Probably it is a big Yes! This is because navigation, which in loose sense is *moving from A to B* is integral part of your daily life. Navigation is the natural process you learn as a small child [2] and develop as you grow up. Human navigation requires both wayfinding (the cognitive act of getting from *here* to *there*) and locomotion (the physical act of getting from *here* to *there*). On an aggregate level, this activity is mobility [3]. Mobility is vital to accomplishment of activities of daily living (ADL).

People may lose mobility because of disabling diseases such as stroke or neuromuscular malfunction. *Intelligent wheelchairs* (IW) are presented as a solution to the lack of independence suffered by such mobility impaired individuals. Intelligent wheelchairs can be seen as robotic systems which assist a person to move from one place to another. IW are an integral part of rehabilitation robotics. Rehabilitation is of utmost importance for disabled population. To maintain and/ or improve their quality of life through robotics is the main thrust of research under the field of rehabilitation robotics.

To play the role of a *rehabilitation robot*, one of the requirements of an intelligent wheelchair is to keep individuals active and prevent them from residual skill loss. Medically, it is prescribed that assistance must be provided on need basis. For an intelligent wheelchair, it is particularly important that the system should not only adapt the level of assistance but also perform in such a way that the user is unable to realize that he is getting help! Such a notion is termed in literature as “feeling in control” [4]. It is desirable that a system must take full advantage of user’s potential abilities. This is often addressed by a *collaborative approach.* The thesis starts out with the following observation–

Most of the current collaborative approaches for wheelchairs control [5],[6], [7] ignore the basic fact that human act independently (of the system) and are often satisfied with a good solution (which may not be optimal), a phenomenon that is called satisficing[8].

In line with what is been being propounded by Schultz and his group [9][10], this thesis is based on a belief that:

“In human and machine collaboration, to effectively collaborate the machine must be cognitively enhanced”

It is worth noting that, the thesis follows a stream similar to what is being propound from the introductory quote of Pat Langley. Artificial intelligence (AI) started out with the vision that a computational system with the cognitive abilities would share the same breadth of abilities as humans. A System that is designed without understanding of cognitive process of human will miss the objective of AI.

1.2 Motivation

collaborate

1. To work together with others to achieve a common goal.
2. To voluntarily cooperate treasonably, as with an enemy occupation force in one’s country.

http://en.wiktionary.org/wiki/collaborate

As quoted, there are two meanings of the word “collaborate”. The first meaning is relevant for this thesis. More precisely, to give an idea of how collaboration is to be understood, here is an example from daily life:

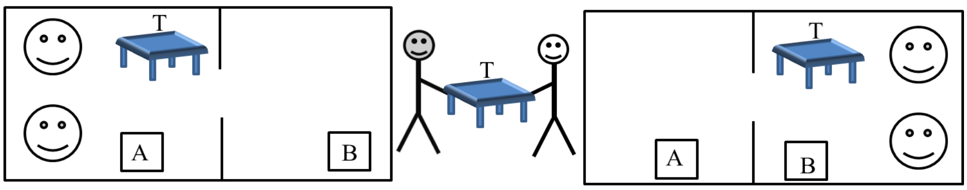

Figure 1-1: Move a table from A to B

Suppose you X and your friend Y are arranging your home. Let there be a dining table T in room A. You want to place it in room B. So, you ask your friend about this. Of course, you and your friend know how to carry a table. You both position yourselves on opposite end of T and lift it. Suppose your friend lift it first and then you initiate lifting the other side of T. You and your friend carry the table by holding T in a comfortable position. Both of you are using your minimum physical effort to hold and carry the table. While carrying the table, your friend feels the weight of the table not as heavy as you are experiencing. Your own movement influences the movement of your friend, who is on the other end of T. You maintain your grip on the table to balance and monitor position and movements of T.

While carrying T, at some point, you are feeling uncomfortable as weight of T is heavy for you. So you decide and change the current position of your hand to grip T. In the mean time your friend observes that the table is leaning. So your friend grip tightly and adjust his body and hand position to balance the table position.

When going through the doorway D, Y notices that the way you currently hold T will not fit through the doorway. In other words, your friend knows that your current holding position of T is not correct. So your friend adjusts his hand and body without your deliberative attention. So you adjust your end of the table in a way friend of yours want. In other words, your friend helps you to hold the table correctly so that it fit through doorway. It happens in a way that you are even unable to realize that you are getting help!

Now table T is in room B. The activity that you and your friend performed to move the table is called collaboration. The activity that your friend perform to manage the table movement supports the concept of collaboration of this thesis. In such activity, you do not feel that you are alone in control of the table movement.

During the activity the variation of control is felt by each in its own actions. The sense of feeling in control experienced by you is due to the collaboration in control of table movement.

Instead, imagine that you are an intelligent system and find yourself in a room A and you know that Y wants to carry the table to Room B. You position yourselves on one end of T, opposite to Y. Y lift T first and then you initiate lifting the other side. You maintain your grip on the table and monitor the table movement's. Each step, you also observe your own as well as Y movements.

Suppose, when going through the door way, you notice that the way Y currently holding T will not fit through the doorway. You know that Y is not correctly holding T. So you adjust your hand and body position to grasp T. It is obvious that Y adjusts his end of the table in a way you want. So, you help Y to hold T correctly so that T fits through the doorway.

It is not that you are controlling Y's action. The "feeling in control" experience by Y is due to the collaboration in control of table movement. This is because, you are collaborating in control of the table movement.

The plan you had executed satisfy the way Y control the table movement with X. This is because you have a set of abilities to engage in a joint action with Y. More specifically, you have following abilities

- *You know what Y is doing.*
- *You know how Y is doing the task.*
- *You know what are the way that Y can do the task.*
- *How Y should accomplish the task.*

You executed control actions, when you find out Y might be in a condition where he is unable to give directives to you. You are a kind of cognitive agent. In other words, you are intelligent so you behave like a teammate, who understands Y's conditions, what Y is going or trying to do, and whether Y's intent or action matches the situation. Most importantly you know how to help Y. During the task, you collaborate with Y to achieve a common goal leading to collaborative control of table movement. You are a kind of intelligent system that supports the concept of collaboration of this thesis:

"In human and machine collaboration, when needed machine should help human team member"

We derive our motivation for this thesis: propose a framework to equip the machine with abilities as like you. In this thesis, we explore collaborative control mechanism to establish interaction between wheelchair user and cognitive agent based wheelchair in navigation. Incorporation of such framework within an intelligent wheelchair helps in achieving human machine collaboration.

1.3 Objective

The thesis is within the field of rehabilitation robotics; more precisely–motivated by the collaboration between human and machine. Figure 1-2 shows where the focus of this thesis is placed. A concise statement is the following:

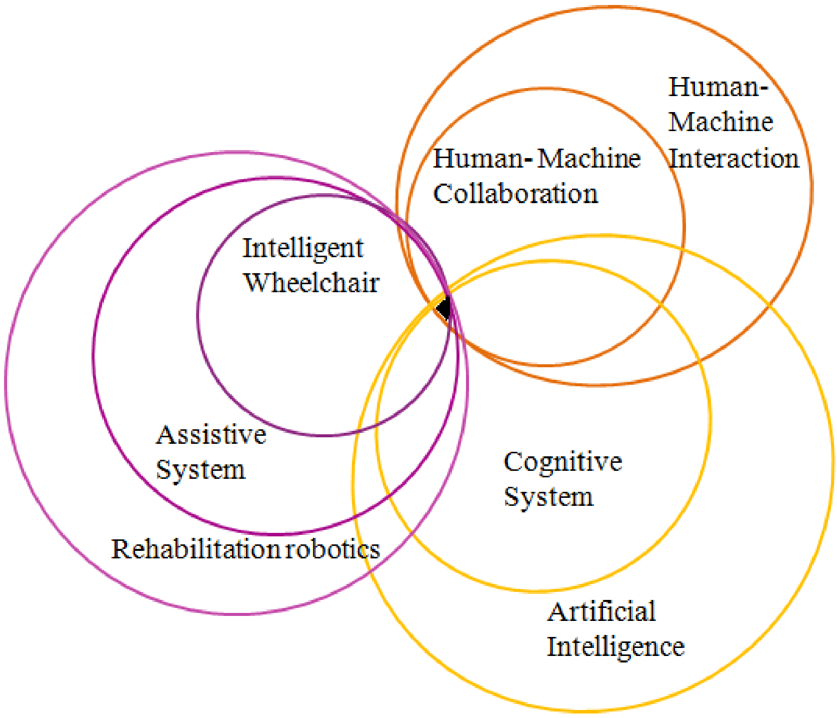

Figure 1-2: The thesis centers on cognitively enhanced control in human-machine system as indicated by the dark area in the figure.

> *The thesis put forwards architecture for cognitive collaborative control of navigation.*

The framework aims to establish cognitively enhanced collaborative control for an intelligent wheelchair. The main approaches towards accomplishment of the objective are enumerated as follows:

- **Extending a traditional agent structure for collaboration**. The starting point of the work is an agent architecture building on the belief- desire-intention model (BDI). This work extends BDI agent to enable collaboration.

- **Study human wayfinding to formulate strategies for agent navigation**. As agent move towards being collaborative in navigation task, the basic ingredients for such behavior is agent's knowledge of human strategies to getting from *here* to *there*. In this context, we explore wayfinding in a virtual maze. The knowledge of human strategies from empirical investigation thus gained form part of the extended BDI agent.

- **An architecture for cognitively enhanced collaborative control**. To present how the extended BDI agent and the facts of human wayfinding influence a controller design for collaborative navigation. The facts learned from empirical investigation are stored as knowledge base for extended BDI agent. The controller architecture aims to establish cognitive collaborative control for an intelligent wheelchair.

1.4 Thesis Overview

The thesis is organized into the following chapters:

- **Chapter 2: Literature review.**

  Chapter 2 presents related work relevant to this research work.

- **Chapter 3: cBDI: Extended BDI agent for human agent collaboration.**

  Chapter 3 centers on how a traditional agent architecture can be extended to effectively collaborate with a human team member in the context of human–machine system. The traditional agent architecture chosen here is Belief–Desire–Intention model.

- **Chapter 4: Empirical Investigation of Human Navigation.**

  The work reported in Chapter 4 aims to broaden our understanding of human behavior in execution of navigation tasks in order to achieve more intuitive human–machine collaboration. Human centric strategies are derived (strategies that are derived from empirical investigation of wayfinding) that would form part of the *human centric strategy library* of the cBDI agent–makes the agent to know set of *human strategies* that a human can execute.

- **Chapter 5: C^3Arc: cBDI Based Cognitive Collaborative Control.**.

  Chapter 5 aims to put forward a control architecture to accomplish collaborative navigation. cBDI agent forms the core of the control architecture.

The architecture aims to implant cognitive collaborative control for an intelligent wheelchair. Evaluation of cognitive collaborative control is presented in this chapter.

- **Chapter 6: Conclusion and Future Work.**

  Chapter 6 make general conclusions and give perspectives on future work.

1.5 Contributions

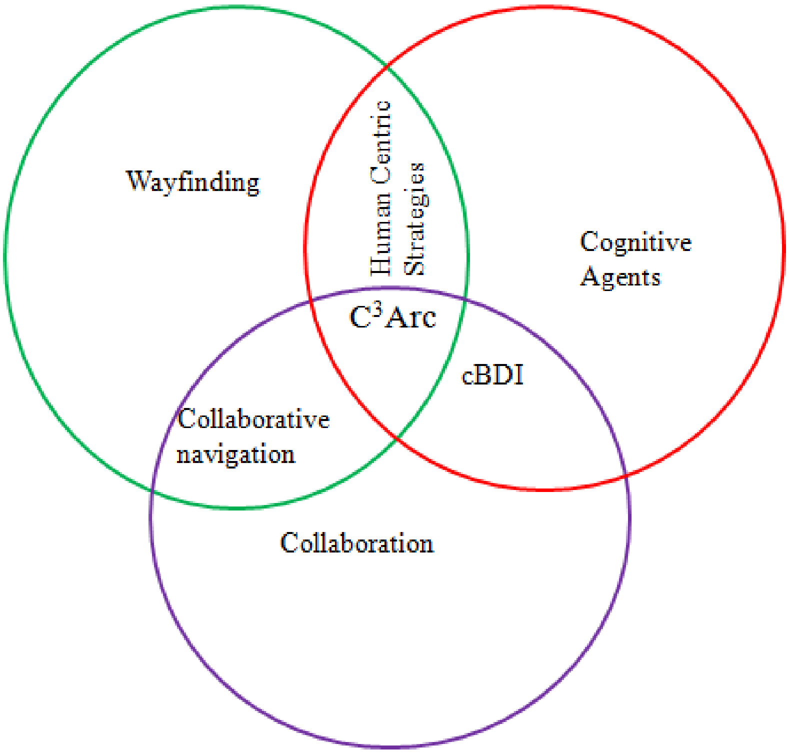

Figure 1-3: The diagram depicts contribution of the thesis.

The contribution of this thesis is best illustrated by Figure 1-3 shown above. The main contribution of this thesis is putting forward C^3Arc-a cognitive collaborative control framework. This required work to be undertaken in three areas depicted by the circles: a. Human Agent Collaboration b. Cognitive Agents and c. Human Wayfinding.

cBDI- an extended BDI architecture: As shown by the intersection of Collaboration and Cognitive Agents, the dissertation contributed to extending BDI architecture. The thesis presents cBDI - an extended BDI architecture to facilitate Human Agent Collaboration.

Human-centric Strategy: This dissertation has explored human wayfinding behavior with the goal of identifying strategies that a human use. And introduced human-centric strategy for the cBDI agent (through introduction of a strategic state planner) so as to be able to construct human-like plans.

Collaborative Navigation: This dissertation has presented a framework that is based on the extended BDI architecture and the wayfinding strategies learned from empirical investigation to control a wheelchair in a way the user wants to control. The control framework is based on requirements in establishment of collaborative navigation.

Finally C^3Arc is evaluated through human subject studies.