Representing and Reasoning about Complex Human Activities - an Activity-Centric Argumentation-Based Approach

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Ph.D. Thesis

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Paintings:
Author: **Edmundo Rosero Burgos**; country: Colombia

Front Title: THE PALENQUERA. Technique: Oil on canvas. Description: This is a woman direct descendent of African slaves, who sells fruits in the city of Cartagena Colombia. A usual job in this city, women from Palenque dedicated to sale sweets and fruits. Palenque, near Cartagena town was a place where black slaves fleeing from their masters creating a free people town that still retains some African traditions. Palenque is considered a symbol of resistance.

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Abstract

The aim of this thesis is to develop theories and formal methods to endow a computing machinery with capabilities to identify, represent, reason and evaluate complex activities that are directed by an individual's needs, goals, motives, preferences and environment, information which can be inconsistent and incomplete.

Current methods for formalising and reasoning about human activity are typically limited to basic actions, *e.g.,* walking, sitting, sleeping, etc., excluding elements of an activity.

This research proposes a new formal activity-centric model that captures complex human activity based on a systemic activity structure that is understood as a purposeful, social, mediated, hierarchically organized and continuously developing interaction between people and word.

This research has also resulted in a common-sense reasoning method based on *argumentation*, in order to provide explanations of the activity that an individual performs based on the activity-centric model of human activity. Reasoning about an activity is based on the novel notion of an *argument under semantics-based inferences* that is developed in this research, which allows the building of structured arguments and inferring consistent conclusions.

Argumentation is a kind of defeasible reasoning that allows the generation of potentially conflicting explanations (arguments) with different strengths, which are evaluated using different semantics to find the most likely and consistent explanation.

Structured arguments are used for explaining complex activities in a bottom-up manner, by introducing the notion of fragments of activity. Based on these fragments, consistent argumentation-based interpretations of activity can be generated, which adhere to the activity-centric model of complex human activity.

For resembling the kind of deductive analysis that a clinician performs in the assessment of activities, two quantitative measurements for evaluating *performance* and *capacity* are introduced and formalized. By analysing these qualifiers using different argumentation semantics, information useful for different purposes can be generated. *e.g.,* such as detecting risk in older adults for falling down, or more specific information about activity performance and activity completion. Both types of information can form the base for an intelligent machinery to provide tailored recommendation to an individual.

The contributions were implemented in different proof-of-concept systems, designed for evaluating complex activities and improving individual's health in daily life. These systems were empirically evaluated with the purpose of evaluating theories and methodologies with potential users. The results have the potential to be utilized in domains such as ambient assisted living, assistive technology, activity assessment and self-management systems for improving health.

Sammanfattning

Syftet med denna avhandling är att utveckla teorier och formella metoder för att ett intelligent datorsystem ska kunna identifiera, representera, resonera om och utvärdera en människas komplexa verksamheter som är drivna av en individs behov, mål, motiv, preferenser och miljö, vilket är information som kan vara inkonsekvent och ofullständig. Existerande metoder för formalisering och resonerande om mänsklig verksamhet är till största delen begränsad till basala aktiviteter såsom gå, sitta, sova, där sådan information inte tas med i beräkningar.

Denna forskning presenterar en ny formell, aktivitetscentrerad modell som fångar komplex mänsklig verksamhet på basen av en systemisk aktivitetsstruktur som tolkas som en meningsfull, social, medierad, hierarkiskt organiserad och kontinuerligt utvecklande interaktion mellan människor och omvärlden.

Denna forskning har också resulterat i en resonemangsmetod baserad på *argumentation* för att generera motiverade beskrivningar av människans aktivitetsutförande, utifrån den aktivitetscentrerade modellen av mänsklig verksamhet. Resonerande om en verksamhet baseras på en unik definition av argument som hanteras av en semantikbaserad inferensmetod som utvecklats i denna forskning, och som tillåter konstruktion av strukturerade argument och generering av konsistenta slutsatser.

Strukturerade argument används för att ge motiverade förklaringar av aktivitet i en "bottom-up"-ansats genom att introducera begreppet "fragment av verksamhet". Baserat på dessa fragment kan konsistenta argumentationsbaserade förklaringar av verksamhet genereras, vilka följer den verksamhetscentrerade modellen av komplex mänsklig verksamhet.

För att följa den deduktiva analysen som professionella inom hälsovården använder vid bedömning av aktivitet introduceras och formaliseras två kvantitativa parametrar för att utvärdera *utförande* och *kapacitet*. Genom att analysera dessa parametrar med hjälp av olika argumentationssemantiker kan information användbar för olika syften genereras, såsom identifiera risk för äldre att falla, eller mer specifik information om aktivitetsutförande och hur aktivitetens mål uppfylls. Båda typerna av information kan utgöra basen för ett intelligent system att generera personanpassade rekommendationer till individen.

Resultaten implementerades i olika "proof-of-concept"-system, designade för att utvärdera komplexa mänskliga verksamheter och för att förbättra människans hälsa i sitt dagliga liv. Dessa system utvärderades i empiriska pilotstudier i syfte att utvärdera teorier och metoder med potentiella användare. Resultaten kan användas i "smarta hem" och datorbaserade hjälpmedel som syftar till att underlätta vardagen för exempelvis äldre, samt i självdiagnos- och självmonitoreringssystem som syftar till att förbättra hälsa och förmåga att utföra aktiviteter.

Preface

This Ph.D. Thesis consists of the following papers:

Paper I J.C. Nieves, **E. Guerrero** and H. Lindgren. “Reasoning about Human Activities: an Argumentative Approach”. In M. Jaeger et al. (Eds.) Twelfth Scandinavian Conference on Artificial Intelligence. Frontiers in Artificial Intelligence and Applications Vol. 257, pp. 195-204, IOS Press, 2013.[1].

Paper II **E. Guerrero**, J.C. Nieves and H. Lindgren. “Semantic-based construction of arguments: An answer set programming approach”. International Journal of Approximate Reasoning 64 (2015): 54-74.[2].

Paper III **E. Guerrero**, J.C. Nieves, M. Sandlund and H. Lindgren. “Activity qualifiers in an argumentation framework as instruments for agents when evaluating human activity”. In Advances in Practical Applications of Scalable Multi-agent Systems. The PAAMS Collection, PAAMS 2016, pp. 1-12, 2016. Springer International Publishing Switzerland [3].

Paper IV **E. Guerrero**, H. Lindgren and J.C. Nieves. (2013). “ALI, an Ambient Assisted Living System for Supporting Behavior Change”. *VIII Workshop on Agents Applied in Health Care* (A2HC 2013): 81-92, 2013.

Paper V **E. Guerrero**, J.C. Nieves and H. Lindgren. “An Activity-Centric Argumentation Framework for Assistive Technology Aimed at Improving Health”. Journal of Argumentation & Computation. In press[4].

In addition to the papers included in this thesis, other publications were published within the studies but not contained in this Ph.D. thesis, as follows:

Conference papers:

- H. Lindgren, J. Baskar, **E. Guerrero**, I. Nilsson and C. Yan. “Computer-Supported Assessment for Tailoring Assistive Technology”. To appear in Digital Health 2016 Conference Proceedings (DH ’16).

- J.C. Nieves, S. Partonia, **E. Guerrero** and H. Lindgren, “A Probabilistic Non-monotonic Activity Qualifier”, Procedia Computer Science, Volume 52, 2015, Pages 420-427, ISSN 1877-0509.

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- J. C. Nieves, **E. Guerrero**, J. Baskar and H. Lindgren, “Deliberative Argumentation for Smart Environments”, in 17th International Conference on Principles and Practice of Multi-Agent Systems (PRIMA 2014), LNCS, vol: 8861, pp: 141-149 , 2014.

- **E. Guerrero**, J.C. Nieves and H. Lindgren. ALI: an Assisted Living System for Persons with Mild Cognitive Impairment . 26th IEEE International Symposium on Computer-Based Medical Systems (CBMS 2013): 526-527. 2013

Workshop papers:

- **E. Guerrero**, H. Lindgren and J.C. Nieves. “STRATA, a Platform for Evaluating Physical Capacity Based on Triangulation of Multiple Observation Sources”. Workshop on Intelligent Environments Supporting Health and Well-being, part of 13th Scandinavian Conference on Artificial Intelligence. 2015.

- **E. Guerrero**, H. Lindgren and J.C. Nieves. “ALI, an Assisted Living System Based on a Human-Centric Argument-Based Decision Making Framework”. 13th Workshop on Computational Models of Natural Arguments (CMNA 2013): 46-51. 2013.

Licentiate thesis:

- **E. Guerrero**. “Supporting human activity performance using argumentation-based technology”. Umeå University, Faculty of Science and Technology, Department of Computing Science. 2014. ISBN 978-91-7601-136-2. ISSN 0348-0542. UMINF 14.20.

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Now in Spanish.

Esta tesis es un esfuerzo conjunto de las familias Guerrero y Rosero. Creo que muchas personas debería agradecer pero me quedaría corto. Esta tesis tiene una dedicatoria, para mi mami Maria Eugenia que siempre, desde el inicio me ha apoyado en proyectos como estos, viajar para estudiar. La adoro. Especial agradecimiento va para mi tio Edmundo que siempre me apoya y a puesto su talento en la carátula de este libro. Debo agradecer de todo corazón a Sara, que me ha apoyado en momentos difíciles. Te quiero.

Contents

Glossary

Ubiquitous Computing Ubiquitous computing has as its goal the non-intrusive availability of computers throughout the physical environment, virtually, if not effectively, invisible to the user [144].

Human Computer interaction Human computer interaction is an area of applied cognitive science and engineering design. It is concerned both with understanding how people make use of devices and systems that incorporate computation, and with designing new devices and systems that enhance human performance and experience [31].

Artificial Intelligence The field for the study and design of intelligent agents, where an intelligent agent is a system that perceives its environment and takes actions that maximize its chances of success [124].

Argumentation theory The theory of argumentation is a rich, interdisciplinary area of research spanning across philosophy, communication studies, linguistics, and psychology. Its techniques and results have found a wide range of applications in both theoretical and practical branches of artificial intelligence and computer science. These applications range from specifying semantics for logic programs to natural language text generation to supporting legal reasoning, to decision-support for multi-party human decision-making and conflict resolution [117].

Belief-Desire-Intention model In the study of agent-oriented systems (intelligent agents), a Belief-Desire-Intention architecture views the system as a rational agent having certain *mental attitudes* of Belief, Desire and Intention, representing, respectively, the information, motivational and deliberative states of the agent [118].

Defeasible Reasoning Reasoning is defeasible, in the sense that the premises taken by themselves may justify the acceptance of a conclusion, but when additional information is added, that conclusion may no longer be justified [112].

Logic Programming Logic programming is a method for representing declarative knowledge. A logic program consists of rules. A rule has two parts: the head and the body. If the body is nonempty, then it is separated from the head by the symbol $\leftarrow$ ("if"): $Head \leftarrow Body$. Major logic programming language families include Prolog, Answer set programming (ASP) and Datalog. When a body of knowledge is expressed as a logic program, *logic programming systems* can sometimes be used to answer queries on the basis of this knowledge [81].

Argument Arguments are defeasible: the reasoning that formed a persuasive case for T, in the light of changes in viewpoint or awareness of information not previously available, may subsequently fail to convince [16].

Strong Negation Strong negation is sometimes called "explicit" negation or even "classical" negation, commonly represented by $\neg$.

Negation as failure Negation as Failure is a special inference rule commonly represented by *not* in Answer set programming literature. The evaluation of *not* a is true whenever there is no reason to believe a, whereas $\neg a$ requires a proof of the negated atom. An intuitive reading of *not* a represents a possibly incomplete state of knowledge [82].

Acronyms

ADL *Activities of Daily Living*

AmI *Ambient Intelligence*

AAL *Ambient Assisted Living*

AST *Assistive Technology*

HCI *Human-Computer Interaction*

AT *Activity Theory*

ELP *Extended Logic Programs*

WFS *Well-Founded Semantics*

KR *Knowledge Representation*

AAF *Abstract Argumentation Frameworks*

***i*AT** *intelligent Assistive Technology*

NAF *Negation as Failure*

AI *Artificial Intelligence*

CL *Classical Logic*

Chapter 1

1. Introduction

This thesis addresses the general problem of representing and reasoning about complex human activities, for the purpose of providing intelligent, computer-based support tailored to an individual conducting an activity.

A *complex human activity* is a purposeful activity driven by needs and directed by motives specific to the individual. Skiing for health or social acceptance purposes, can be considered an example of a complex activity with different underlying motivations, conducted to achieve goal-directed actions, *e.g.,* skiing a target distance of 90Km. Computer-based systems for tracking the movement of a skier are popular nowadays. However, a complex activity is conducted in a given context, its goal-directed actions are limited in time, and the motives and needs behind the activity can change. Due to this, a reliable evaluation of such complex activity cannot be obtained using such kind of sensor-based systems only by tracking skiing movements. Moreover, conflicting motives and needs can lead to define contradictory goals related to an activity: aiming for better health by skiing, yet maintains his/her health-threatening habit of smoking. Consequently, given the scale of the complexity of the activities to evaluate, a computer-based system needs to be, "intelligent" enough and flexible enough to: 1) obtain a representation of the activity; 2) deal with uncertain and incomplete sensor data; 3) explain the current state of the individual conducting the activity; and 4) resemble the kind of deductive analysis that a human expert, *e.g.* a therapist or a clinician performs in the assessment of activities, in order to appear valid and reliable as clinical evidence.

1.1 Problem statement

Current methods for formalising and reasoning about human activity are limited to basic actions and simplistic models that exclude person-specific features that direct and determine an activity [2, 136]. Moreover, most of them do not handle conflicting purposes or changing conditions. Therefore, the evaluation of complex activities based on basic actions and overly simplified models are not reliable and its utility may be questionable and limited.

Objective

The objective of this research is to develop theories, methods and instruments that can identify, represent and evaluate complex activities based on information, which includes information about an individual's needs, goals, motives, preferences and environment, and which can be inconsistent and incomplete.

The following research challenges and related research questions are addressed in this thesis. The first two relate to how representing a complex activity:

Challenge 1: Formalize the concept of complex activity. How represent and define the concept of complex human activity to be used as a knowledge structure for a software agent[1]?

Challenge 2: Syntax language for capturing an activity. What kind of specification language should be used to capture a complex activity by an intelligent agent in order to manage uncertain and incomplete information?

Other challenges addressed in this thesis relate to reasoning with different kinds of information for deciding what activity is being performed and evaluating the performance, this for the purpose to decide what action to be performed by an assistive software agent.

Challenge 3: Reasoning about complex activities. How provide consistent explanations about an ongoing activity, considering different information sources and rejecting hypotheses when new stronger contradictory information comes?

Challenge 4: Evaluating activity execution. How measure the achievement (non-achievement) degree of an activity and its current status?

Challenge 5: Tailoring the behaviour of an intelligent software agent to the individual's needs and preferences. How provide personalized assistive services oriented to the activity that an individual performs?

An activity-centric approach is taken to address the complexity of human purposeful activity, following activity-theoretical models [48, 70, 80]. In order to address the uncertainty and incompleteness of the context information, a logic-based *declarative* programming language[2] is used. Potentially conflicting purposes of complex activities are solved by applying a formal argument-based inferences [42].

The results are expected to be utilized in domains such as *Ambient Assisted Living* (AAL), *Assistive Technology* (AST), activity assessment and self-management systems for improving health.

In the remaining part of this thesis, related concepts to representation and reasoning about complex activities, from the perspective of an *intelligent agent*, are intuitively introduced in Chapter 2. Chapter 4 summarize the contributions of this thesis. A comparative

[1] Shortly, an *agent* can be defined as a computer system that is capable of performing *autonomous action* in an environment in order to meet its design objectives, using sensors for capturing information about the world. A more accurate definition will be provided in Chapter 2

[2] Roughly speaking, a declarative program can be seen as a representation to describe *what* a computer-based system must to do to solve a problem, not *how*. A definition of a declarative programming language will be intuitively presented in the following Chapter.

discussion about the research contributions with respect to the state of art is presented in Chapter 5. Based on the presented contributions, different research lines as future work are outlined in Chapter 6.

Chapter 2

2. Representing and Reasoning about Complex Human Activities

In this Chapter different theories and formalisms are introduced as a background to the contributions presented in Chapter 4. The chapter is organised based on the research challenges identified in the Introduction. Section 2.1 presents different approaches for representing human activities, first presenting a social sciences perspective for describing purposeful activities: Activity Theory. This theory among others in social sciences, establishes an important difference regarding the notion of a human activity compared to current approaches in *Artificial Intelligence* (AI). The representation of a complex activity presented in this chapter is an integral part for all the presented contributions.

Reasoning processes to be used by an intelligent agent are introduced in Section 2.3. Roughly speaking, two approaches are investigated inspired by a type of reasoning that a person often performs, withdraw conclusions in the presence of new information. These formal methods enable intelligent systems make inferences given a knowledge base even in the presence of uncertainty, incomplete and inconsistent information. These methods were used for developing a new approach for argument-based reasoning presented in Paper II, which were extended in Papers III-V to reasoning about complex activities.

2.1 Representing Complex Human Activities

In this research, a *complex human activity* is the unit of analysis when representing and reasoning about the real-life human praxis. An activity is a systemic and structured set of processes with a common objective describing the interaction between an individual and the world that surrounds her/him. It accounts for the motivations behind the activity, a minimal meaningful context for individual actions, and the goals to achieve. Providing meals for the family and take a walk with the dog can be seen as complex activities. People they have motives and needs behind their actions, and when the objective is achieved the activity ends. In order to resemble the assessment of human behaviour that a therapist or clinician performs[1], an *activity-centric* analysis of an individual must be applied, which requires information about the individual's preferences, needs, motives and her/his environment.

[1]See [50] for methods and approaches in Physiotherapy and Occupational Therapy for the assessment of human activities.

Complex activities change with time and are developed into a routine when the expertise is achieved. For example, a *rookie* skier plans every *action* of the arms and legs, the individual is aware of all the ski poles movements trying to follow a well-known technique as a *goal* reference. With practice, a "good" technique is acquired where the individual becomes unaware of the specific skiing details, which have transformed into a routine. Only when the individual loses the rhythm the awareness returns and s/he starts focussing in the balance and propulsion techniques. The intuition behind this suggests a dynamic relationship between different elements: actions, goals and routinised *operations* building up the activity (Figure 1). Moreover, these elements are also connected with needs and motives. If the *objective* is earn social status through the skiing, this status also motivates the individual to perform an activity.

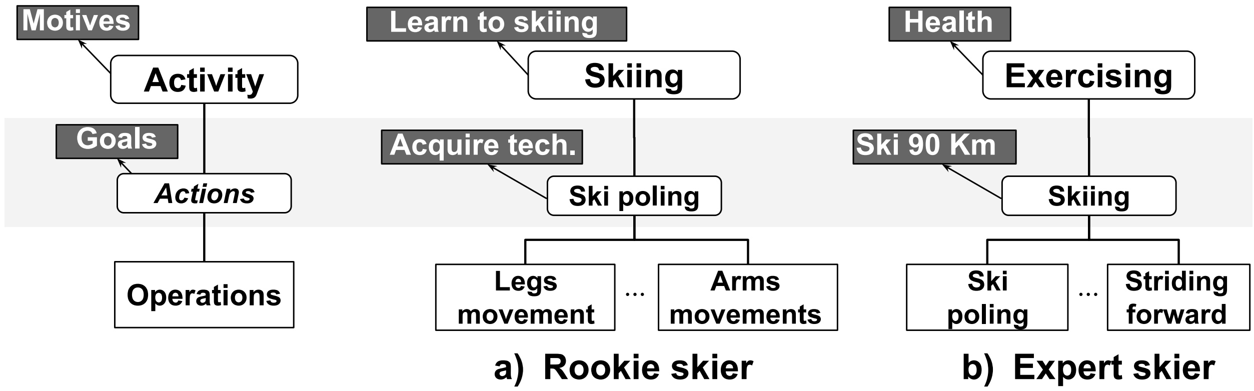


Figure 1: Skiing exercising structures

Suppose that the rookie tracks her/his performance with the help of a computer-based system, and assume that the systems has sensors to detect the skier movements. The dynamics of a complex activity cannot be represented for a static list or sequence of atomic elements of the activity such as actions or operations. Moreover, under this notion of complex activity, a general static classification of physical activities to be used by a system for tracking activity is questionable, because the activity is framed and is dependent on particular situations of the individual and her/his world.

A sensor captures limited information of the world. Such uncertainty leads to an incomplete representation of the individual in her/his environment. There is not one single computational method/approach to identify and represent every detail of the skier by using sensors, this computational problem have been investigated since the rise of *Artificial Intelligence* (AI) [95, 99, 120]. In fact, McCarthy and Hayes in the seminal paper for AI literature [95] uncovered a problem that has haunted the field ever since: *the frame problem*. The problem arises when logic is used to describe the effects of actions and events [127]. It is a problem of representing what remains unchanged as a result of an action or event. In this sense, different reasons have been identified regarding the difficulty of representing knowledge using logic formalizations: [83]:

- It is difficult to become aware of all the implicit knowledge; that is, to make this knowledge explicit. For example, establish what are the reasons behind the execution of an activity, needs, motives are implicit.

- There is some knowledge that is difficult to express in any formal language. In order to infer about something, it is required to specify minimal characteristics about it, such as its current status. Needs and motives can be difficult to define or establish.

- Deciding the necessary knowledge, what basic elements are necessary to organize in a knowledge base and how to organize them is a complex enterprise.

- It is hard to integrate existing knowledge. There are various technical difficulties, mainly assumptions that have been built into each domain and captured in a specific formal language, *e.g., expressiveness* differences between Defeasible Logic [103] and Logic Programming without Negation as Failure [37] which was analysed in [7], or integrate knowledge captured in Web Ontology Language (OWL) with Logic Programming analysed in [101]. See [130] for a review of different approaches in the logic programming *family* for managing uncertainty and/or vagueness.

- Define the elements that change in a domain and what remains unchanged as the result of an action of an agent. In AI the word *fluent* (from the Latin *fluent*: flowing) is a common term for referring to an aspect of the world that changes.

From a computational point of view, uncertainty and incompleteness of information representing a complex activity is a problem. Not all the computational formalisms for representing knowledge can manage uncertainty and incompleteness of the information. Statistical inference approaches can handle uncertainty and inconsistent information of some elements human activity such as movements. Some approaches based on *data-driven methods* to infer information from a dataset have been widely investigated (see [1, 2, 89, 136] among others). In fact, when knowledge is represented by logic formulas, each formula represents a *belief* held by an agent. A set of formulas is then viewed as a belief base. Adding a new belief to a belief base comes down to discarding worlds that become impossible. The more beliefs are available, the smaller the set of possible worlds and the more precise the information. However, in data-driven approaches, each piece of data corresponds to an observed state of the world. In contrast, each model of a belief base represents a potentially observable world only. Moreover, in the data-driven view, data are interpreted as examples, and are not necessarily mutually consistent in a logical sense since gathered data can be easily dissonant [41]. Gathering data about all the different elements of a complex activity of an individual for obtaining probabilistic models or patterns is debatable. Data-driven methods have shown important results in the inference of information using uncertain sensor-based data; however, the proposed methods in this research add important value in the mission to understand human behaviour, and for generating sense-making behaviour and explanations.

Activity Theory is a systemic theory about complex human activities, developed within the psychology and human-computer interaction fields. Activity Theory provides models for describing humans in activity from an activity-centric perspective. Activity Theory considers a structured representation of an activity, oriented to accomplish a motive (see Figure 2). An activity consists of a set of *actions*, where each action is oriented towards fulfilling a goal. Actions are consciously aimed at fulfilling specific *goals* and occur in a limited time span. Actions are necessarily a part of an activity and can be transformed into an activity if its goal becomes an objective to the individual. Consequently, the definition of what an activity and an action are, becomes a matter of interpretation of the situation of the

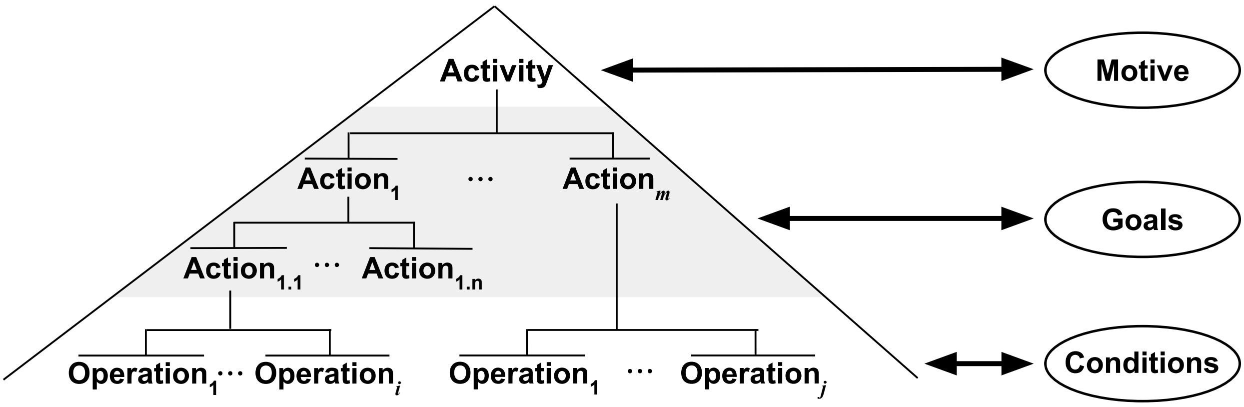


Figure 2: The hierarchical structure of activity (adapted from [70]).

individual. An action consists of a set of sub-actions and/or a set of operations. *Operations* do not have their own goals; rather they provide means for execution and adjustment of actions to particular situations [67]. Operations may emerge through the *automatization* of actions, which become routinised and unconscious with practice [70], such as the example of the rookie skier previously mentioned in Chapter 1.

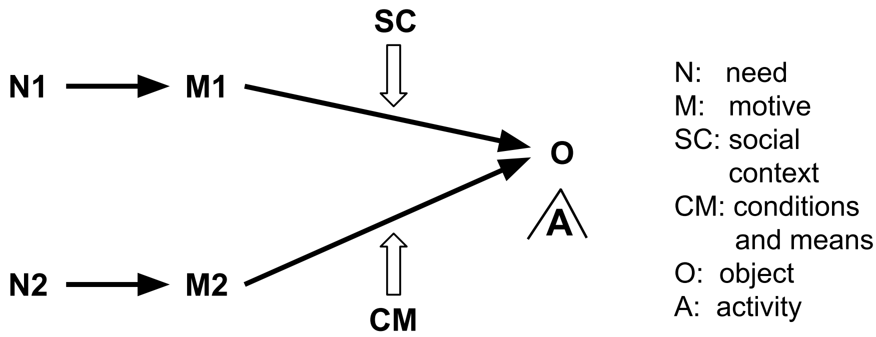


Figure 3: Relationship among needs, motives, objects and the hierarchical activity structure (adapted from [70]).

The interaction among an individual's motives, needs, social and context factors *w.r.t.* the structured activity hierarchy is represented in Figure 3. In order to exemplify this model, consider the example of the skier, which attempts to meet two needs: social inclusion: N1, and health: N2, in a given social context: SC, under certain conditions and having certain means: CM. In this case the individual attempts to achieve two motives, M1 and M2 related with the objective to improve health and social status (O) at the same time through the activity of skiing (A). The initiation of a conscious goal (goal acceptance or goal formulation) constitutes the starting point of an action; it concludes when the actual result of the action is evaluated in relation to the goal. This understanding allows for the depiction of a continual flow of activity, divided into individual units. Actions can be described in terms of a recursive loop structure, with multiple forward and backward interconnections [15]. Figure 4 presents a simplified model of action as a one-loop system.

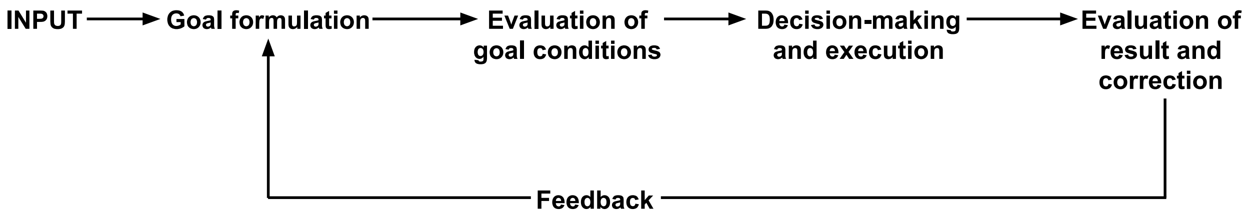


Figure 4: Simplified model of action as a one-loop system (adapted from [15]).

2.2 Intelligent Agents Reasoning about Complex Activities

A software *agent* can be defined as a computer system that is *situated* in some *environment*, and that is capable of performing *autonomous action* in this environment in order to meet its design objectives [147]. An *intelligent* agent, is in addition *reactive*, *proactive*, *social*, *robust* and *flexible* [107, 146]. Most of the intelligent agent-systems in the AI literature use different sensor-based methods for capturing information about the world.

An agent tracking an individual's complex activities requires capability to: 1) reasoning about the activity being performed; the agent is expected to detect and decide which activity is being conducted; 2) evaluate the quality of the activity performance. For this, the agent needs methods of decision-making, for instance resembling therapist assessment; 3) reason and make decisions about how to act upon new information, *e.g.*, modify or adjust its tracking method, or provide the person with supportive messages tailored to the individual's needs and goals. The formalism for representing the knowledge of an intelligent agent, determines capabilities and restrictions about the agent's internal behaviour. Ideally, an intelligent agent should be able to "understand" the physical activity that a person is performing. If the individual asks the agent about her/his skiing performance, the request is a detailed algorithm, and its output spells out *how* to satisfy such request and *what* needs to be done. The agent must to have knowledge and the inferring ability to figure out the exact steps, that will satisfy the request and execute them. The languages for spelling out *how* are often referred to as *procedural* while the languages for spelling out *what* are referred to as *declarative* [12]. Mathematical logicians formalized declarative knowledge long before the advent of the computer age, their formal languages were not sufficiently expressive to describe for example, the knowledge of a complex activity, being logicians unaware about the possibility of automated reasoning. In this sense, *Classical Logic* (CL) has been extensively used as a specification language to represent declarative knowledge. However, CL embodies the *monotonicity* property according to which the conclusion entailed by a body of knowledge stubbornly remains valid no matter what additional knowledge is added [12]. Monotonicity is relevant in the design of an intelligent agent *reasoning* in dynamic domain context such as the performance of complex activities.

In AI, formalisms for representing human activities have been proposed since the introduction of the field. A number of approaches in AI literature ([5, 74, 51, 75, 65] among others), considers the detection and evaluation of human activities by means of finding patterns, sets, trajectories or sequences of *atomic* representations of human behaviour. One example is when the tasks: grasping a cup, then rising the cup, then move cup close to lips, are considered a drinking activity in [64]. While this makes it relatively easy to design laboratory experiments, the use of isolated actions in analysing real-life situations outside a laboratory is less fruitful [77]. Indeed, some approaches using atomic representations seem to have difficulties in accounting a systemic approach, that includes social *artifact-mediated* or cultural aspects of purposeful human activity. Also the notion of time tends to be reduced to relatively discrete slices, often described by given goals or tasks. The continuous, self-reproducing, systemic, and longitudinal-historical aspects of human functioning seem to escape most theories of action [48].

Research suggests that humans perform *plan inference* and that plan inference contributes to much of the intelligent processing done by humans [29]. Plan *libraries* encoded recipes as collections of preconditions, constraints, goals, subgoals, and effects of actions [73]. In *plan recognition* unlike in *planning*, *the recognizer* generates a description with details of the setting, and predicts the goals and future actions of other agents [72]. Plan recognition can be classified into two main categories, namely *intended* plan recognition and *keyhole* plan recognition in terms of Cohen *et.al.* [33]. In the first kind, the recognizer assumes that the agent is deliberately structuring his activities in order to make his intentions clear, *i.e.,* the recognizer assumes that the individual knows that s/he is being observed and is adapting her/his behaviour in order to make her/his intentions clear to the recognizer. Consequently, this form of recognition supposes a cooperative effort on the part of the observed entity. In the second case, one supposes that the individual does not know that s/he is being observed or that s/he is not taking it into account, hence the analogy of someone being observed through a keyhole [23]. In a keyhole approach, conclusions are justified on the basis of observation-based evidence, the recognizer's knowledge, and a limited set of explicit assumptions called "close world" assumptions in AI literature. Under a closed world assumption, certain answers are admitted as a result of failure to find a proof. For example, in an airline database, all flights and the cities which they connect will be explicitly represented. *Failure* to find an entry indicating that Air Canada flight 103 connects Vancouver with Toulouse permits one to conclude that it does not [119]. On the other hand, in an "open world", data is represented by clauses, and negative data is listed explicitly in the database. Answers to queries may be either looked-up or derived from the data. A problem arises in that negative data may overwhelm a system [98].

The representation of the knowledge of an intelligent agent determines the model of reasoning. The design of intelligent agent-based systems, able to capture a systemic approach of human behaviour, endowing to the agent an *activity-centric* perspective is computationally difficult given the structure dynamics of an activity. In AI the first step in the design of intelligent agents is to decide what structure the world is regarded having, and how information about the world and its laws of change will be represented in the machine [95].

In Section 2.1, some reasons about why "belief-based" approaches were selected instead of data-driven methods, regarding the knowledge representation of complex activities were outlined. The use of Argumentation Theory with machine learning methods was compared by Longo and co-workers in [91]. They highlight the following advantages of argumentation theory compared to data-driven approaches:

- Inconsistency and Incompleteness: argumentation theory provides a methodology for reasoning on available evidence, even if partial and inconsistent; missing data is simply discarded and even if an argument cannot be elicited, the argumentative process can still be executed with remaining data. This is powerful when a dataset is corrupted;

- Expertise and Uncertainty: argumentation theory captures expertise in an organised fashion, handling uncertainty and the vagueness associated to the clinical evidence, usually expressed with natural language propositions/statements;
- Intuitiveness: argumentation theory is not based on statistics/probability being close to the way humans reason. If the designer is anyway inclined to use statistical evidence, this can be modelled as an argument included in an argumentation framework; vague knowledge-bases can be structured as arguments built with familiar linguistic terms;
- Explainability: argumentation theory leads to explanatory reasoning thanks to the incremental, modular way of reasoning with evidence. Argumentation theory provides semantics for computing arguments' justification status, letting the final decision be better explained/interpreted;
- Dataset independency: argumentation theory does not require a complete dataset and it may be useful for emerging knowledge where quantity evidence has not yet been gathered;
- Extensibility and Updatability: argumentation theory is an open and extensible paradigm that allows to retract a decision in the light of new evidence: an argumentation framework can be updated with new arguments and evidence;
- Knowledge-bases comparability: argumentation theory allows comparisons of different subjective knowledge-bases. Two clinicians might build their own argumentation framework and identify differences in the definition of their arguments.

2.3 Argument-Based Reasoning about Human Activities

Common-sense reasoning is the type of reasoning that a person often performs when reasoning about what to do, by evaluating the potential results of the different actions s/he can do [94]. The encoding of common-sense knowledge has been recognized as one of the central issues of AI since the inception of the field by authors such as McCarthy [92]. Most computer-interpretable representations assume either complete information or information that is partial only along some very limited dimensions. By contrast, common-sense reasoning requires dealing with a wide range of possible types of partial information [36].

Inspired by common-sense reasoning, *non-monotonic reasoning* captures and represents *defeasible inference*, *i.e.*, that kind of inference of everyday life in which reasoners draw conclusions tentatively, reserving the right to retract them in the light of further information [6]. A large number of non-monotonic reasoning approaches have been developed for capturing common-sense knowledge [93, 96, 100, 120, 90, 69, 104]. Among them, *Extended Logic Programs* (ELP) [55] captures incomplete information as well as exceptions, extending CL with *strong negation* and *Negation as Failure* (NAF). CL has been extensively used as a specification language to represent declarative knowledge. However, CL embodies the monotonicity property according to which the conclusion entailed by a body of knowledge stubbornly remains valid no matter what additional knowledge is added [12].

The knowledge base of an intelligent agent modelled using an ELP program, can be seen as a set of logical propositions. For instance, it is possible that the individual is exercising because there are information (evidence) that s/he is not at her/his home, also sensors detect that s/he is jogging and there is no evidence that s/he is walking. An ELP clause can be defined for this particular example as follows:

$$is\_Exercising \leftarrow is\_outofHome \wedge is\_jogging \wedge not\ is\_walking$$

NAF is identified as the connective (*not*), capturing the notion of lack of information and uncertainty. The same example can be seen in a more *succinct* form as: *e.g.,*

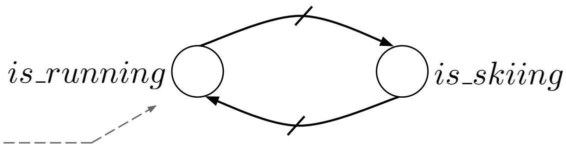
$$e \leftarrow h \wedge j \wedge not\ w$$

which should be understood as "*e is* true *if h and j are true and there is no evidence that w is* true". A logic program can be viewed as a specification for building theories of the world, and the rules can be viewed as constraints these theories should satisfy.

As any language, a knowledge specification language such as ELP has two essential aspects: 1) a *syntax*: determined by atomic symbols, objects such as constants or variables, functions and connectives, *e.g.,* $\{e, h, j, w\}, \leftarrow,\ not$; and 2) the *semantics* of the language: the "intended" meaning of a sub-set or the whole program.

Semantics of logic programs can be seen in the way they define satisfiability of the rules [13]. This means that the goal of a logic programming semantics is to determine the conditions under which a set of propositions is true or false. A number of semantics have been defined for logic programs with different deductive inference behaviour (see [38, 39] for a review and classification of different semantics in logic programming). For example, the knowledge base of an intelligent agent implemented in a sports application may be defined by the following program P^2.:

$$P := \left\{ \begin{array}{c} is\_Exercising_g \leftarrow is\_outofHome \\ is\_outofHome \leftarrow not\ is\_walking \\ \boxed{\begin{array}{c} is\_running \leftarrow not\ is\_skiing \\ is\_skiing \leftarrow not\ is\_running \end{array}} \end{array} \right\}$$



With this program and a set of additional information such as sensor based observation data, the agent may determine if an individual is out of her/his home or if the individual is exercising or not. Informally speaking, the two last clauses: $is\_running \leftarrow not\ is\_skiing$, and $is\_skiing \leftarrow not\ is\_running$[3], represent a "loop" in which positive and negative literals are connected generating a cycle, they are "deadlocked", each waiting for the other to either succeed or fail. Cycles through literals have been analysed in logic programming literature [84, 116, 139], and used as "test cases" to analyse the behaviour of different semantics.

[2]Graphical notation: dependency relationship through negation as failure is represented with the arrow: and a dependency through positive atoms with the arrow:

[3]An intuitive reading of the first clause would be: "*the agent infers that an individual is running if there is not evidence that the individual is skiing*", the second clause has a contrary reading.

For instance, the aforementioned program P under some *skeptic* semantics (*Well-Founded Semantics* (WFS) [140] among others) infers that the individual may be exercising, or being out of home, but refraining to draw any conclusion about if the person is running or skiing. The contrary behaviour, being *credulous*, *i.e.,* drawing a conclusion for all can be obtained with Stable semantics [54] among others. This behaviour was empirically explored in Paper III, for evaluating which semantics could be most suitable in the evaluation of physical performance.

$$Q := \left\{ \begin{array}{c} is\_Exercising \leftarrow is\_outofHome \\ is\_outofHome \leftarrow is\_jogging \wedge not\ is\_walking \\ is\_running \leftarrow not\ is\_skiing \\ is\_skiing \leftarrow not\ is\_running \\ is\_Cooking \leftarrow is\_inKitchen \wedge is\_still \\ is\_inKitchen \leftarrow not\ is\_bathroom \end{array} \right\} \quad \begin{array}{l} Q_1 := \left\{ \begin{array}{c} is\_Exercising \leftarrow is\_outofHome \\ is\_outofHome \leftarrow is\_jogging \wedge not\ is\_walking \\ is\_running \leftarrow not\ is\_skiing \\ is\_skiing \leftarrow not\ is\_running \end{array} \right\} \\ Q_2 := \left\{ \begin{array}{c} is\_Cooking \leftarrow is\_inKitchen \wedge is\_still \\ is\_inKitchen \leftarrow not\ is\_bathroom \end{array} \right\} \end{array}$$

Figure 5: Illustration of the Relevance principle using WFS

An important characteristic of WFS is the *relevance* property, which states informally speaking, that it is perfectly reasonable that the truth-value of an atom, with respect to any semantics, only depends on the *subprograms* formed from the *relevant clauses* with respect to that specific atom [40]. An example of relevance is presented in Figure 5, where the truth-values of atoms in subprogram Q_1 do not depend on the values of Q_2, *i.e.,* given a knowledge base Q it is possible to infer that an individual is cooking in the kitchen, regardless the inconsistency of some rules in Q_1. This result was used in contribution Paper II to infer relevant information under incomplete and inconsistent knowledge bases. In this setting, it is clear that underlying formalisms for knowledge representation and reasoning play a fundamental role, especially in the presence of inconsistent and incomplete information, *e.g.,* sensor-based data or negative/positive cycles. Inconsistency in knowledge-based systems may be present for different reasons [19]:

- Contradictory information in the knowledge base (*e.g.,* opposed goal-actions in an activity: smoke and running for improving health).
- Observations conflicting with the normal functioning mode of the system.
- Discrepancies in the reliability of knowledge bases (*e.g.,* different sensor-based services providing the location of a person, with different levels of accuracy).

Argumentation theory has emerged as a formalism for dealing with non-monotonic reasoning. Dung has demonstrated in his seminal paper [42], that many of the major approaches to non-monotonic reasoning are different forms of argumentation. An *argument* is the basic and fundamental element in Argumentation theory built by a structure consisting of a tuple *support-conclusion*.

The non-monotonic reasoning performed through argumentation is based on the notion that arguments distinguish themselves from mathematical proofs by the fact that they are *defeasible*, that is, the validity of their conclusions can be disputed by other arguments [14]. A general argumentation reasoning process can be summarized as follows (see Figure 6):

- (Step 1) Generation of a set of arguments using an underlying knowledge base. The result is an *argumentation framework* (AF) represented as a directed graph in which the internal structure of the arguments, as well as the nature of the attack relation has been abstracted away. An AF determines in which ways these arguments attack each other.
- (Step 2) Based on this argumentation framework, the next step is to determine the sets of arguments that can be accepted, using a pre-defined criterion corresponding to a selected *argumentation semantics*.
- (Step 3) After the set(s) of accepted arguments have been identified, one then has to identify the set(s) of accepted conclusions.

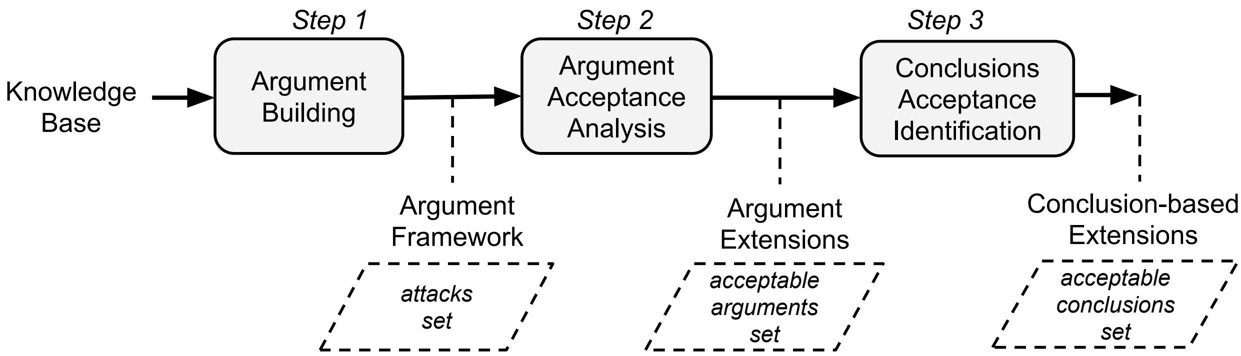


Figure 6: Argumentation reasoning process

Traditionally, the non-monotonic process in argumentation is performed in the argument acceptance analysis (Step 2 in Figure 6). For example, considering one agent with different sensor-based sources, reasoning about if an individual is exercising or not. The agent has a knowledge base captured in a program as the previous example P, building two argument-based hypotheses:

$$Arg_1 = \langle \underbrace{\{is\_Exercising \leftarrow is\_outofHome,\ is\_outofHome \leftarrow \top\}}_{Support}, \underbrace{is\_Exercising}_{Conclusion} \rangle$$

$$Arg_2 = \langle \underbrace{\{\neg is\_Exercising \leftarrow not\ is\_running\}}_{Support}, \underbrace{\neg is\_Exercising}_{Conclusion} \rangle$$

Arg_1 infers that individual is exercising because there is evidence that the individual is out of home ($is\_outofHome \leftarrow \top$) and Arg_2 states the contrary given the uncertainty in a sensor to detect that the individual is running ($\neg is\_Exercising \leftarrow not\ is\_running$). Argumentation literature defines this situation as a mutual argument *attack*. The final inference of the agent will be the empty set by choosing a skeptical argumentation semantics (Grounded among others [42]), *i.e.,* there are not consensus for deciding if the individual whether is exercising or not. By contrast, if the agent uses a credulous argumentation semantics (Preferred or

Stable [42] among others) may infer less cautions hypotheses, accepting explanations without a complete agreement but still consistent. The non-monotonicity is exemplified when more evidence is obtained by the agent, for instance adding evidence that the individual is running, which invalidates the second argument. An empirical comparison of credulous and skeptical argumentation semantics was performed to evaluate the achievement of goals in activities, which was reported in Paper III. Moreover, in Paper I the concept of *hypothetical fragments of activities* was defined, to evaluate complex activities using goal achievement. The notion of activity fragment, defined a calculus to evaluate individual's activity performance which was also reported in Paper I.

In argumentation literature, given a program P a set $S \subseteq P$ is *consistent* iff $\nexists \psi,\ \phi \in P$ such that $\psi = \neg\phi$[4]. Intuitively, the aim of structured arguments is to prevent sub-arguments containing *counter-factual* information, *i.e.,* two sub-arguments attacking each other within an argument. The approach for building arguments presented in Paper II prevents this phenomenon by evaluating the support of every sub-argument. A number of consistency conditions have been proposed for rule-based systems, particularly for argumentation theory [27, 45]. Furthermore, in Paper II a set of rationality postulates for argument-based systems under ELP, serving as a quality recommendation for logic-based argument systems, specifically in terms of logic programming approaches are introduced.

2.4 Evaluating Activities Using Argumentation Theory

Researchers in the healthcare and sports science domains have developed and validated structured instruments for evaluating human activities. These instruments influenced the development of the general approaches for evaluating activities using argumentation theory introduced in Paper I and III.

In the health domain, the practice of *evidence-based medicine* means integrating available clinical evidence from systematic research into clinical practice. External clinical evidence may both invalidate previously accepted diagnostic tests and treatments and replace them with new ones that are more powerful, more accurate, more efficient, and safer [125]. Particularly, in the Physiotherapy and Occupational therapy areas, an *assessment* is a core component of the therapy processes. Assessment "describes the overall process of selecting and using multiple data-collection tools and various sources of information to inform decisions required for guiding therapeutic intervention during the whole therapy process" [50]. Indeed, in different clinical practices such as the evaluation of health and functioning, setting goals and evaluating treatment outcomes, standardization of evaluation assessment is the norm. The World Health Organization provides the International Classification of Functioning, Disability and Health (ICF) [105], a framework for measuring health and disability at both individual and population levels [106]. Among others aspects, ICF describes the interaction of human activities with *environmental factors*, and *personal factors*, *e.g.,* preferences, needs and motives (Figure 7).

ICF, describes different factors influencing the health condition of an individual, that

[4]Definition 6. *Consistent set* in [27].

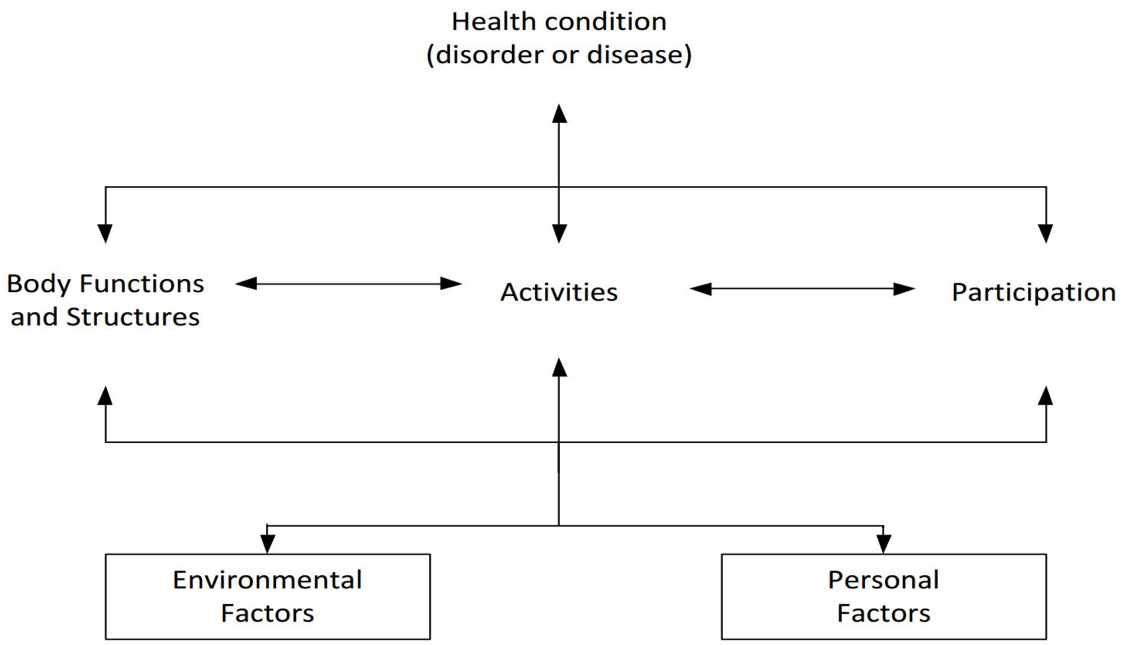


Figure 7: The ICF Model: Interaction between ICF components (adapted from [106])

partially corresponds to the perspective of Activity Theory. Moreover, ICF also defines two quantitative measurements for describing the functioning of an individual, the so called *Performance* and *Capacity qualifiers* [106]. The Capacity qualifier "describes an individual's ability to execute a task or an action", or, more specifically, "the highest probable level of functioning that a person may reach in a given domain at a given moment" [108]. A therapist applies the Capacity qualifier in the context of a "uniform or standard environment, and in this way it reflects the environmentally adjusted ability of the individual" [105]. The Performance qualifier describes "what a person does in her/his current environment" [105][5]. These ICF qualifiers were generalized and formalized in Paper III.

The ICF and Activity Theory perspectives regarding what is an activity and its evaluation are not the only instruments for assessing disorders. In the Occupational therapy literature, different frameworks, some of them an amalgam of behavioural, cognitive, and contemporary motor theories, such as the Dynamic Performance Analysis (DPA) [111] are iterative processes, carried out as the client (an individual) performs the occupation (a complex activity in terms of Activity Theory), with the purpose of to identify where performance breaks down and test out solutions [111]. In the Sports Science field, the evaluation process of *physical activities* can be seen from the Activity Theory perspective, as a bottom-up approach. Firstly, a physical activity is closely related to, but distinct from *exercise*. Exercise is a subset of physical activity defined as "planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness" (see [32] for further comparison among definitions). In the Sports Science literature, a number of approaches evaluate physical activities identifying "low-level" actions linked to different metabolic processes such as energy expenditure, etc. [78]. In this field, it is assumed that physical activity movements respond to an underlying motive (motive as Activity Theory

[5]Another way to describe this qualifier is "involvement in a life situation" or "the lived experience" of a person in the environment [108].

term) [138, 129, 122].

The notion of bottom-up evaluation from some sports performance evaluations, corroborated the intuition behind the hypothetical fragments of an activity presented in Paper I.

2.5 Conclusions

In this Chapter different formalisms were introduced for representing and reasoning about the information related to a complex activity.

In this thesis, the task of representing knowledge about complex activities is a crucial task. Information about an individual's social interactions, context, needs and motivations to conduct an activity, among other factors, define a *complex* structure. Researchers within the fields of psychology, social and cognitive sciences have developed systematic approaches for studying human behaviour, proposing different methods to describe the interaction of a subject and the world that surrounds her/him, *e.g.* [109, 145, 79]. The systemic approach of Activity Theory seems suitable for the representation of complex activities [85, 87]. Some of the structural components that describe a complex activity in Activity Theory such as: goals and actions have similarities with a well-known model for modelling a rational agent in AI, the so-called *Belief-Desire-Intention model* (BDI) [24].

The challenge for using a complex model of an activity as a knowledge representation for an artificial agent relies at least on three factors: 1) an activity is a structure which comprises a number of elements which are difficult to capture, quantify or predict, for example: the abstraction of needs and motives, the uncertainty of operations and the inconsistency of some goal-based actions; 2) the dynamics of different elements in an activity; the shift between consciousness to unconsciousness (and vice versa) create a complex dynamism of an information structure (*e.g.,* the Rookie and Expert skier problem in Figure 1); and 3) variety of technical issues to obtain information about individual's activities; sensor-based approaches capture limited information; interviews, questionnaires or/and self reports such as those used in health care, require an expert interpretation to be captured by a rational agent.

Endow common-sense reasoning capabilities to a rational agent is one of the main research lines of AI. Underlying formalisms for representing and reasoning under inconsistency and incomplete information is a cornerstone in this thesis. A number of non-monotonic approaches have been developed for capturing common-sense knowledge [93, 96, 100, 120, 90, 69, 104]. Among different formalisms, Argumentation Theory has emerged as a non-monotonic reasoning model. Arguments are defeasible elements which can be extended to capture pieces of knowledge, which can be seen as atomic explanations of a knowledge base.

Evaluation of complex activities by rational agents, such as is usually performed in the health domain, is currently neglected in AI literature. A number of approaches for evaluating activities by experts such as clinicians or therapists have been developed, which follow systematic and standardized processes.

Chapter 3

3. Methods

The purpose of this chapter is to describe the involvement of other domain professionals in the research and summarize the prototypes developed.

3.1 Inter-professional Collaboration and Societal Impact

The process for building *intelligent Assistive Technology* (*i*AT) such as ALI: an Ambient Assisted Living System (Paper IV-V) has been characterized by a close cooperation with health and sport science domains experts. Particularly, the design, development and test of tools such as *Balansera* [59] and *STRATA* [58] were supported by experts of the Physiotherapy department of Umeå University.

The knowledge acquisition was done through informal interviews with professionals which helped in the capture of requirements process.

The methodological process that this thesis followed contain different steps:

1. Initial hypotheses: definition of initial hypotheses and research problem. Support regarding relevant literature and the initial approach was obtained from health-related experts (Physiotherapy and Sport Science).

2. Design: identification of the knowledge representation approach, investigation and definition of new or *state of art* formal methods for knowledge reasoning. Selection of appropriate technology and tools for prototyping. Health experts cooperate in the human-computer interaction design of the prototypes.

3. Development: prototyping of tools based on initial designs is performed. Laboratory tests are performed to evaluate consistency of the outputs with respect to the design and stability. In this process, health experts are consulted for updates on the initial design.

4. Test: experimental pilots are performed using participants and volunteers which are firstly assessed by Physiotherapy experts. Data regarding experiments is collected using the designed tools.

5. Data analysis and approach evaluation: initial hypotheses are contrasted with data findings. Results of the pilot tests are discussed and analysed in close collaboration with experts.

The methodological process was iterative, adjusting the prototype to new formal method findings or when expert opinion was changing pilot approaches.

An initial prototype called *Physical activity tracker* was developed in collaboration with researchers at the Sports School at Umeå University. This prototype is an automatic tool for evaluating the execution of sports activities, particularly the prototype is intended to measure the quality in the *squats* execution. A new version of this prototype is being developed, following an intelligent-based approach, applying methods of reasoning presented in Paper II and the notion of qualifiers described in Paper III. This prototype will consolidate the knowledge obtained in previous implementations.

A method for measuring exposure to vibration was also developed and implemented in a mobile application called *SmartVib*. This project was a collaboration with researchers at the Department of Occupational and Environmental Medicine at Umeå University among others. This prototype followed a similar process as implemented in the Balansera application in Paper III.

3.2 Prototypes Developed for Evaluating Complex Human Activities

Different formal approaches for reasoning and evaluating human activities were explored as well as a number of prototypes were built to test different formalisms. In Table 3.1, a number of developed prototypes are described.

In the ALI, Balansera, STRATA, Physical activity tracker and SmartVib prototypes information of the user, such as needs and preferences were obtained from a knowledge base platform called ACKTUS (Activity-Centered Modelling of Knowledge and Interaction Tailored to Users) [88]. ACKTUS was developed for enabling health professionals model domain knowledge to be used in knowledge-based applications, and design the interaction content and flow for supporting different types of activities (*e.g.*, diagnosis, risk assessment, support for conducting *Activities of Daily Living* (ADL)) [86]. ACKTUS contains a number of knowledge-bases, assessment applications and dedicated user interfaces for different knowledge domains. All ACKTUS applications share a common core ontology, which is a representation of knowledge at the levels of *activity* and *actions*, in terms of the complexity hierarchy model of human activity provided by Argumentation theory.

Different pilot evaluation studies were performed to test ALI and Balansera, addressing different research questions: 1) how does information about the context, preferences and personalized suggestions contribute to building argument-based explanations about an activity? 2) how is the human-computer interaction performed through a mobile phone? and 3) how does the user react to an intelligent support system? In ALI, these questions were partially answered, based on the analyses of data obtained by ALI and other tools, such as ACKTUS I-Help and through interviews with the test subjects. Results of pilot study performed with ALI platform are presented in Paper IV and V. Balansera was used in two different studies as a tool for support in the assessment of legs strength for older adults [35, 128]. Results of

Name	*Primary Investigation Focus*	*Field or scope*	*Pilot tests*		*Source*
			Numb. Subjects	*Environment*	
Argument Builder [Paper II]	Method for building “semantic-based” arguments based on the Well-Founded Semantics	Argumentation, Logic Programming	-	-	Open source
ALI [Paper IV-V]	Evaluation of a behaviour change monitoring and formal approaches for decision-making	Physiotherapy, Occupational therapy, Sport Science	2	Home-care	Partially open sourced
Balansera [Paper III]	Evaluation of an automatic tool for evaluating activities	Physiotherapy	Phase 1: 10 Phase 2: 20	Laboratory	Open source
STRATA [*]	A platform for evaluating physical capabilities based on triangulation of multiple observation sources	Physiotherapy, Occupational therapy, Sport Science	-	-	Closed
Ume-Act [**]	Evaluation of a tailored motivation-based approach for supporting physical activities	Physiotherapy	10 persons (expected)	Home-care	Open source (expected)
Physical activity tracker [***]	Evaluation of an automatic tool for evaluating indoor and outdoor sport activities	Sport Science	Not defined yet	Sports Science	Open source (expected)
SmartVib [****]	Evaluation of a tracking method of hazardous vibration levels and a recommender system	Mining Industry	10 industries (expected)	Mining industry	Closed

* STRATA platform is an initial exploration to improve ALI platform using multiple agents. STRATA was presented in the 13th Workshop on Intelligent Environments Supporting Health and Wellbeing. In 13th Scandinavian Conference on Artificial Intelligence (SCAI 2016), 2016.

** Ume-Act is under laboratory testing and it will be tested in May 2016.

*** The Physical activity tracker is partially implemented and it is expected to be fully implemented and tested in 2016.

**** A version of SmartVib mobile application was tested in laboratory at CS department at Umeå University

Table 3.1: Different prototypes developed in this research.

the pilot study presented in [128] were used to evaluate complex activities and are presented in Paper III.

Chapter 4

4. Contributions

The following is a summary of the major contributions of the thesis:

1. An activity model for representing complex activities of the human actor.
2. A general argument-based formal model for reasoning about complex activities.
3. A qualifier-based approach for evaluating complex activities.
4. Prototypes for evaluating human activity, subjected to user studies with real users and environments.

The contributions specific to each article included in this thesis are summarised in the following sections.

4.1 Paper I: Reasoning about Human Activities: an Argumentative Approach

*J.C. Nieves, **E. Guerrero** and H. Lindgren. In M. Jaeger et al. (Eds.) Twelfth Scandinavian Conference on Artificial Intelligence. Frontiers in Artificial Intelligence and Applications Vol. 257, pp. 195-204, IOS Press. (2013).*

In Paper I, a novel approach for evaluating goal-based activities is presented. A generic calculus for evaluating the achievement of goals in complex activities was introduced and formalized. This approach is the first proposed argumentation-theoretical method for evaluating performance in complex activities.

The concept of *hypothetical fragments of activities*, following the ideas of Activity Theory, which suggests that an activity is motivated by needs was established. A two-step procedure for the best hypotheses selection was defined: Step 1) *local selection*: extending the Dung's meta-interpreter for selecting hypothetical fragments of activities; and Step 2) *global selection*: determining which sets of hypothetical fragments of activities could form evidence about the fulfilment or non-fulfilment of some particular activity. Moreover, the behaviour of generic argumentation semantics and Dungs argumentation semantics w.r.t.

activity recognition is studied. This calculus is intended to be the underlying approach to evaluating the person's activity performance in AAL systems.

The main contributions of this paper are:

- The integration of Activity Theory and argumentation theory.
- An extension of Dung's argumentation approach for capturing Activity Theory.
- A calculus for evaluating achievement of goals in complex activities.

4.2 Paper II: Semantic-based Construction of Arguments: an Answer Set Programming Approach

E. Guerrero*, J.C. Nieves and H. Lindgren. International Journal of Approximate Reasoning 64: 54-74. (2015).*

The second paper establishes the notion of an argument under the Well-Founded semantics and Stable semantics inferences. This "semantic" process for building arguments allows us to identify a minimal knowledge to infer a consistent conclusion. The approach to evaluate consistency in the argument building process is an advancement compared to previous approaches for building arguments. The major result of this article is a new method for building structured arguments. This method consists of the following:

- The concept of argument under answer-set programming by considering a semantic interpretation of the argument supports is introduced and formalized. This notion allows us to unequivocally identify arguments with stratified programs as support, even when the input for an argument building engine is a non-stratified program. This argument building process can be performed using any logic programming semantics which coincides with stable model semantics in the class of stratified logic programs.
- A set of rationality postulates for argument-based systems under *Extended Logic Programs* (ELP) was introduced. These postulates judge the consistency of the underlying formalisms for building arguments. These postulates are formulated in terms of argument conclusions, considering at the same time a skeptical output of the system. Quality criteria in terms of normal logic programs and a definition of closure of a set of clauses that consider the Gelfond-Lifschitz reduction were introduced and formalized.
- By taking advantage of the computational properties of WFS, an implementation which as far it is known, it is the first argumentation engine for ELP. Therefore, this engine can serve as a starting point for other argument-based systems in a wide application spectrum, such as decision-making frameworks and context-based argument reasoning[1].

[1] The "Argument Engine" is available in: http://www8.cs.umu.se/~esteban/wfsArgEngine

4.3 Paper III: Activity Qualifiers in an Argumentation Framework as Instruments for Agents When Evaluating Human Activity

***E. Guerrero**, J.C. Nieves, M. Sandlund and H. Lindgren. To appear in the Proceedings of the 14th International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS-16). (2016).*

The third paper describes the development of generic methods for detecting and evaluating goal-based complex activities. In particular, an empirical exploration to answer which argumentation semantics are suitable for measuring performance and capacity was performed in this paper. The exploration was framed using a specific goal-based activity in healthcare domain. The contributions of this paper can be summarized as follows:

- An extended version of an argumentation-based activity framework [13] to reason with complex activities dealing with uncertainty from sensor data as well as inconsistent knowledge, e.g., two contradictory goals to be achieved in the same activity
- A method for capturing uncertain sensor data in a knowledge base using logic programs;
- Two qualifiers are introduced: Performance and Capacity, which are used for evaluating activity execution by resembling the assessment of physical activities that is performed by a therapist;

Results of the pilot study in Paper III show that:

- The Capacity and Performance qualifiers can be defined in scenarios where observation-based and goal-based assessment tools are used supported by sensors. The SPPB as well as other assessment tools [34, 56, 60, 62, 110, 121] is a test where the whole evaluation is composed by the quantification of: 1) the achievement of each exercise (goal achievement), and 2) the ability in the execution (captured operations). Capacity and Performance can capture and evaluate such structured assessment from both perspectives.
- There is a considerable difference between the values of the Performance and Capacity qualifiers when different argumentation semantics are considered. Given that the process of hypothesis argument selection can be performed by different semantics, the behaviour of the qualifiers evaluation follows a skeptic or strict manner (in the case of Grounded) or a more credulous approach (in case of Stable, Preferred or Complete) evaluation. In the evaluation of Performance qualifier, Stable provided 65% more values than Grounded and in Capacity evaluation Stable gave 30% more.

4.4 Paper IV: ALI, an Ambient Assisted Living System for Supporting Behaviour Change

***E. Guerrero**, H. Lindgren and J.C. Nieves. VIII Workshop on Agents Applied in Health Care (A2HC 2013): 81-92, 2013. (2013).*

In Paper IV, a prototype of an *Ambient Assisted Living* (AAL) system *ALI: an Assisted LIving system* is presented, integrating the argument engine introduced in Paper I. The approach is exemplified in a case scenario of an individual living in an AAL environment. ALI generates recommendations using information from the observations obtained from the person's environment and from goal-oriented activities, which were selected and prioritized by the person. Contributions of this work are summarized as follows:

- ALI, a modular agent-based ambient assisted living system for supporting behaviour change in mildly depressed and socially isolated individuals.
- A supervised platform for monitoring behaviour change, applied and exemplified for sleeping disorders and implemented for social interaction analysis.
- A situation representation format. A RDF/XML-style format for encapsulate situations, combining stream data systems and traditional knowledge representation approaches.
- A model for capturing evidence about behaviour change in mildly depressed and socially isolated individuals in home environments, integrating ACKTUS knowledge repositories and applications [88].

4.5 Paper V: An Activity-Centric Argumentation Framework for Assistive Technology Aimed at Improving Health

E. Guerrero*, J.C. Nieves and H. Lindgren. To appear in the Journal of Argumentation & Computation. (2016).*

The fifth paper investigates the use of an argument-based decision-making system as part of an activity monitoring-recommender architecture. Activity Theory was used for representing complex activities together with a possibilistic argument-based decision-making framework. A method for persuading an individual to perform activities was introduced and evaluated. The method generated text messages through a mobile application that were aimed to influence an individual for improving her/his health. An approach to generate encouraging and positive feedback messages was developed by using a simple and novel argument-based method. A pilot study was conducted for evaluating the influence of messages in the individual. The main contributions of paper V are the following:

- An integration between a possibilistic argument-based decision framework and Activity Theory is developed and described. Its purpose is to recognize, argue, justify and provide argumentative explanations for human activities.
- Sets of sound argument-based explanations (argument extensions in argumentation literature) are interpreted based on Activity Theory for selecting and formulating messages.

- A real time activity monitoring-recommender sub-system is developed and described, which manages uncertain and incomplete observations of the individual's activity context.

- A modular architecture is described, which is used for recognizing and providing advice on activities to the individuals, supervised by a healthcare team.

- A formative pilot study for evaluating the functionalities of the prototype system ALI involving two potential end users.

Chapter 5

4. Discussion

The major contributions are discussed in this chapter from the perspective of the challenges and research questions specified in the introduction of this thesis. Limitations, advantages and potential impacts of the contributions are also highlighted and discussed.

5.1 Representing Complex Human Activities

Representing human activity is a complex process, when taking human needs, preferences, motives and environment into consideration. The two first challenges identified in this thesis relate to this.

A major contribution of this thesis is the inclusion of an activity-centric paradigm, in the design of intelligent systems. The activity-centric paradigm has been widely used in *Human-Computer Interaction* (HCI) studies [11, 66, 76] among others, but no in *Artificial Intelligence* (AI) being a major impact to the field, particularly to knowledge representation. The activity-centric approach was used in Paper I, and Papers III-V.

Activity Theory was selected among a number of other approaches for different reasons: 1) Activity Theory defines a framework which provides a general perspective to describe and explain different phenomenon about an individual; 2) Activity Theory has been widely used in both theoretical and applied psychology, education and HCI; and 3) The structural components that describe a human actor (motives, goals, needs, actions, etc.) have similarities with one of the most well-known models for rational agent in AI, the *Belief-Desire-Intention model* (BDI) model [24].

The key role of Activity Theory is based on three perspectives:

1. *Physical artifacts mediating external activities*. Activity Theory emphasizes that a human activity is affected by the environment, and dependent on the availability and the characteristics of tools[1], which enable and mediate activity. In this manner, the physical environment is taken into consideration when a human actor is moving around, finding tools to use in activities.

2. *Structured human activity*. Activity Theory defines a hierarchical structure starting from an activity, which consists of a set of *actions*, which in turn may consist of a

[1] An individual animal in its own well-known environment can suddenly recognize a solution to a problem, and come to see an object as a *tool* for some useful purpose [70].

set of actions or *operations* in a nested structure. This activity system is useful for structuring a complex activity formally, both regarding different levels of information, and the dynamics of process.

3. *Changing structure of an activity.* Activity Theory emphasizes the changing nature of an activity and the human ability to perform it, driven by motives, goals, breakdown situations, challenges and focus shifts, which in turn drives development [71]. The description of the changing nature process of a complex activity by Activity Theory, could help to identify and explain variations in the patters of activity achievement when an individual is performing an activity. From the perspective of intelligent agents, variations in the knowledge base structure represents a challenge but at the same time, it provides the opportunity to examine different non-monotonic formalisms for representation and reasoning. Extended logic programs along with WFS seems to be a flexible formalism to deal with a dynamic knowledge base by inferring information only from subsets of a program. In Paper III the use of ELP together with WFS is investigated for evaluating complex activities (see [38, 39] for a more detailed analysis of WFS characteristics *w.r.t* other semantics).

In Paper I, the analysis of observations of the world allows the evaluation of a complex activity in a bottom-up manner. An interesting result of Paper I was the notion a complex activity in terms of goals $\mathcal{A}ct = \{g_1, \ldots, g_i\}(i > 1)$ which was useful to develop a simple and novel calculus for evaluating achievement of goals within an activity. The notion of goal-achievement was also extended in Paper III to define the so-called *qualifiers*. The notion of Capacity qualifier presented in Paper III represents a quantification of observations conducted in an activity. The Capacity qualifier was defined as a quantitative measurement of operations, resembling the analysis of observable evidence that a therapist performs in a physical assessment.

The concept of a qualifier considering complex activities is important for future work and it is considered as a relevant contribution of this thesis, because of its potential functioning as a flexible generic quantitative method to evaluate complex activities.

Different authors have criticized aspects of the "original" Activity Theory [79] introduced by the Russian psychologists Lev Vygotsky and Alexei Leontiev. Research has pointed out issues regarding key concepts: the notion of *object* of an activity [47, 49], problems with poly-motivated activities (multiple motives directing an activity) [70], among others. The problem with poly-motivated activities has been considered in this research, for example in Paper V was analysed a scenario for promoting physical activities with multiple motivations. Results from a pilot test performed in Paper V, showed that goal-based achievement evaluation requires the analysis of the multiple motives behind the activity to have a full perspective of activity evaluation.

5.1.1 Formal Approaches to Capture a Complex Activity

The selection of a formal representation influences the reasoning process, and is a cornerstone in the knowledge representation of intelligent agents.

Capturing a complex human activity implies dealing with inconsistencies in goals, motives, needs within an activity. Uncertain information from observations and incomplete information about the individual's context are common. *Extended Logic Programs* (ELP) have a rich expressiveness through applying negation as failure and strong negation. In Paper II and III ELP was used as the underlying formalism for capturing activities. This represents a major contribution the management of inconsistencies and incomplete knowledge. This approach was further used as a first phase of consistency check for building arguments and hypothetical fragments in Paper II and III respectively.

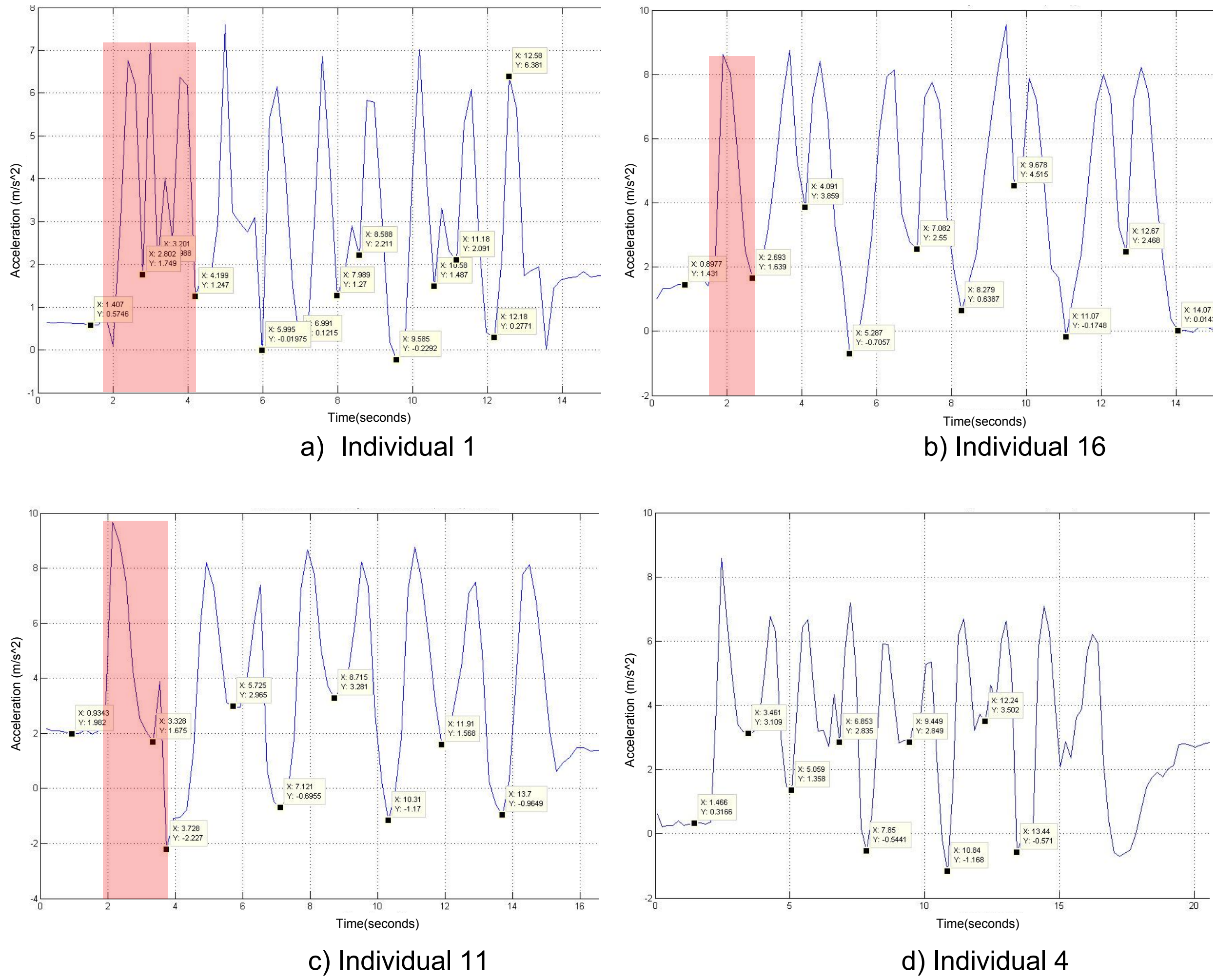


Figure 8: Sensor-based data (acceleration vs. time) obtained in the sit-to-stand test of the SPPB. Red squares highlight the ambiguity of some observations.

Figure 8 shows sensor-based data captured during the conduction of the SPPB test in Paper III using Balansera application. Ambiguity in the data is highlighted with red squares. Balansera analyses peaks in the movement acceleration calculating the initial and final moments of each rising-sitting exercise. The uncertainty in the sensor data to determine starting-ending peaks was captured by clauses such as: $Slow\_Sit \leftarrow not\ Fast\_Sit$ representing incomplete information about an individual in the sitting down phase. In order to evaluate if an individual was "rising fast" or "rising slow", sensor-based data was compared with the assessment evaluation performed by a therapist, defining different parameters of the operations (in Activity Theory terms) such as starting ending points of the movement

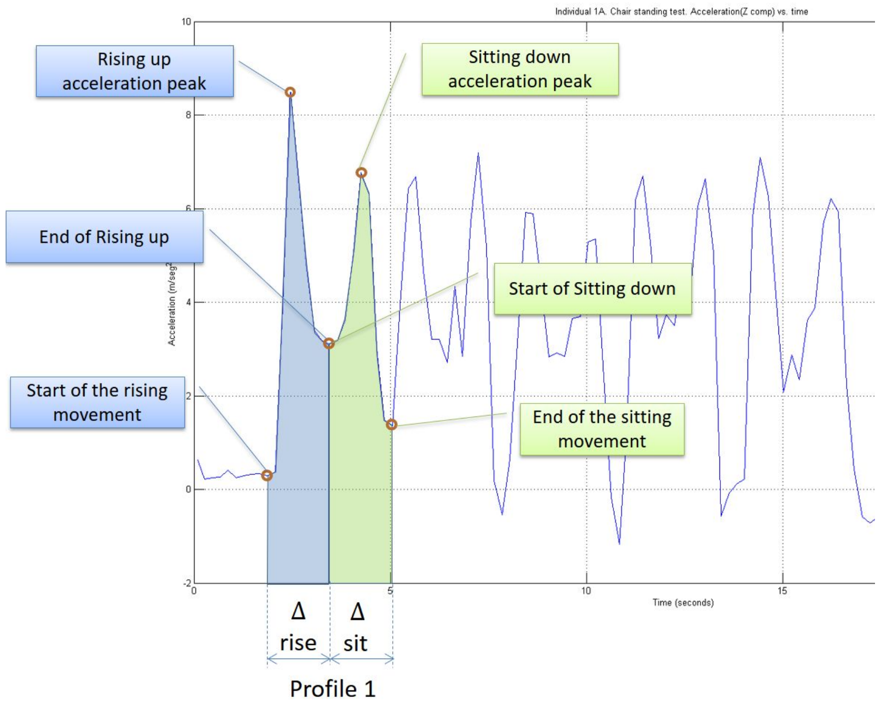


Figure 9: Detail of the sensor-based information describing an operation in the sit-to-stand test of the SPPB.

Table 5.1: Heuristic classification of the speed of rising and sitting is by comparing the Δ rise and Δ sit.

Classification	Data comparison
Slow rise up / fast sitting down	$\Delta Rise > \delta Sit$
Fast rise up / Slow sitting down	$\Delta Rise < \delta Sit$
Same rise up / Same sitting down	$\Delta Rise = \delta Sit$

(Figure 9). Results of the test in Paper III empirically confirm the intuition that different individuals have different patterns of rising up, sitting down movements (see Figure 8).

In the pilot test of Paper III, therapists suggested a classification of the speed of rising up and sitting down comparing the $\Delta Rise$ and ΔSit (Table 5.1.1). Results of this pilot test show that the management of uncertainty using ELP, requires an intermediate step between the "raw" sensor-based data and the knowledge representation using rule-based methods. The heuristic classification suggested by therapists can be considered as such intermediate step, *the expert opinion* which can be captured by different formal knowledge representation approaches including ELP. The heuristic classification and the accuracy of Balansera tool was analysed in [128].

In Paper V, a possibilistic version of ELP was used as underlying formalism to capture human activities. The *theory of possibility* [149] concerns with the meaning of information rather than with its measure. A possibilistic argumentation decision-making framework [102] is based on theory of possibility, using a prioritized set of *goals* for capturing preferences in achieving a particular state in a decision-making problem. The importance of using a

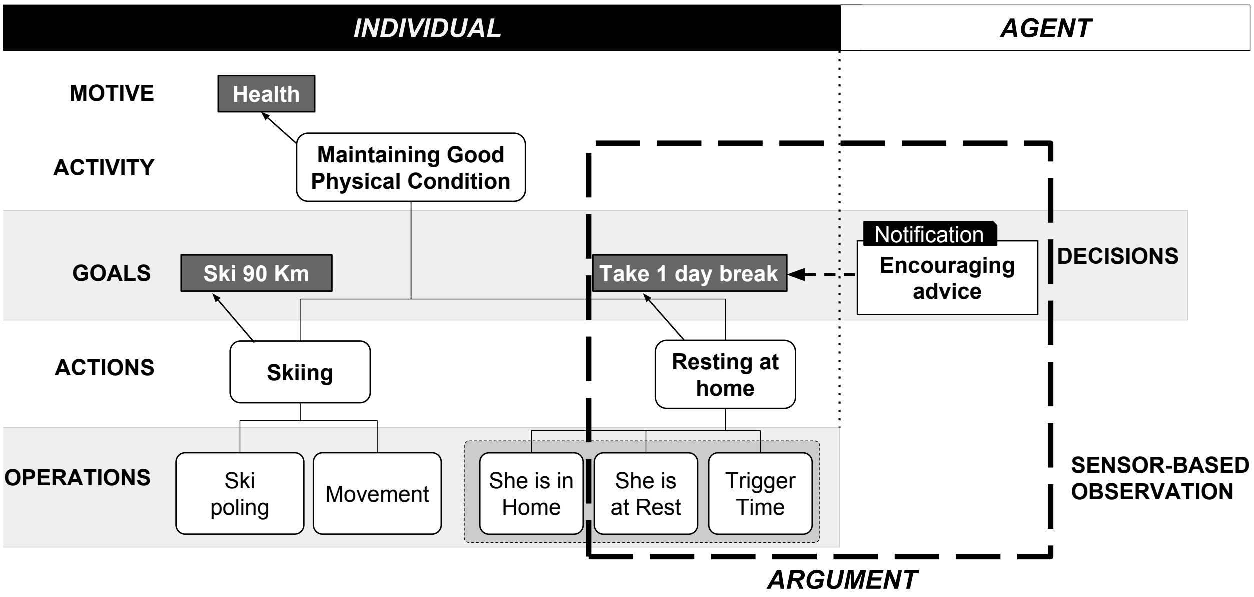


Figure 10: Agent's decisions related to a complex activity.

possibility framework in Paper V relies on the ability of the possibilistic framework to capture individual's preferences among goals, being suitable for representing complex activities when preferences among goals are explicit. In Figure 10, decisions of an agent are directed to individual's goals, preferences among goals and a set of observed operations (bottom part of the hierarchy in Figure 10) allow a selection of the agent's decision. In Paper V, the intelligent agent-system has to decide about to send positive feedback or a persuasive message if it detects the achievement of certain goals, such as is presented in Figure 10.

5.2 Reasoning About Complex Activities

One of the challenges outlined in the introduction is related to how an intelligent agent can reason about complex human activities. In this regard, the semantic-based approach for building arguments presented in Paper II has an important impact for Argumentation Theory community. The answer set programming approach is a novel perspective for building consistent arguments and is as such a major contribution. The importance of this method for reasoning about activities relies on the remarkable behaviour of the *Well-Founded Semantics* (WFS). The *relevance* principle [38, 39, 40] allows to evaluate relevant clauses for an atom, obtaining as result a set of stratified clauses as support for an atom. This result is a major contribution of this thesis because it represents a substantial difference compared to other argument-based approaches for building arguments, where the consistency of structured arguments is evaluated in later phases of the argumentation process, particularly in the argumentation framework construction. The answer set programming approach, evaluates semantically only those relevant clauses to a potential conclusion, this method provides a "consistency-check" at the beginning of the argumentation process generating consistent arguments. A graphical representation of the main contribution of Paper II is presented in Figure 11.

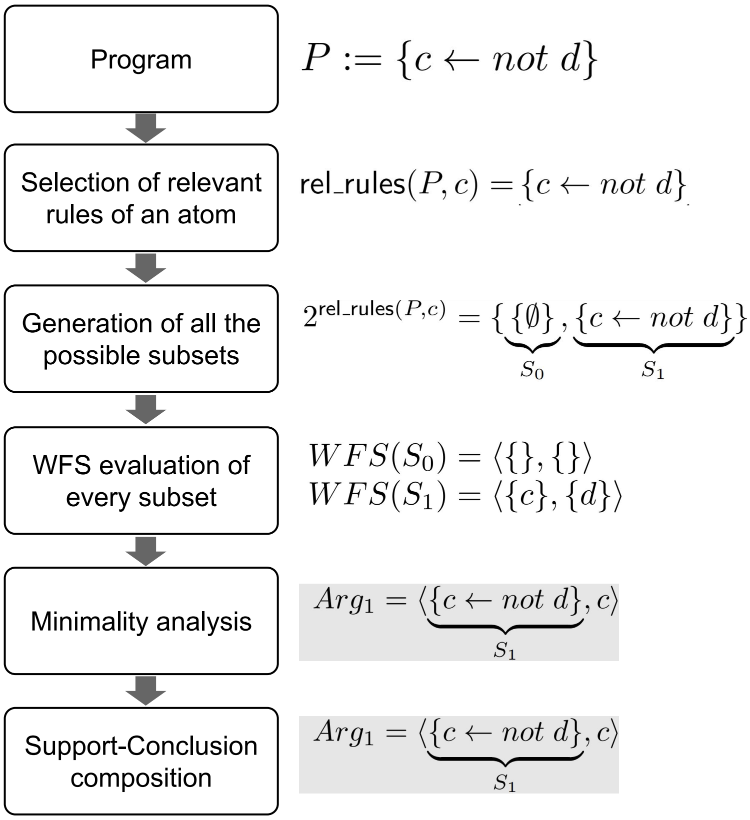


Figure 11: Answer set programming method for building arguments, Paper II.

5.2.1 Different Approaches for Building Arguments

The lack of "consistency checking" during the process of building arguments has been investigated in [45] where it is shown that classical propositional proof systems may propagate conflicts throughout the knowledge bases to unrelated parts. A close approach to the semantic approach presented in Paper II, using a partial evaluation of a program was described in [46]. The main differences between the answer set approach using relevant rules and the notion of a *focal graph* in [46], relies on the underlying specification language and the process for building the structured argument.

An interesting analysis of the nature of structured arguments in terms of ASPIC+ is introduced in [114], which establish the importance of defining argument structures in preference argument frameworks, particularly in those using defeasible rules for inference. Foundational concepts of ASPIC (and consequently of ASPIC+), were derived from the argument structure model introduced in [141] and the attack relationships inspired by [112] and [115]. A difference between the answer set approach in Paper II and ASPIC+ is the method for solving attack relations. ASPIC+ uses a partial preorder on the set of defeasible rules in contrast to the answer set approach which uses inference rules without preferences, maintaining a general level of abstraction without using domain specific preference lineaments.

In [43], three dialectic proof procedures for finding a set of assumptions supporting a given belief are introduced. In this approach, an argument is defined as a deduction whose premises are all assumptions; in this manner, the attack relationship between arguments depends entirely on sets of assumptions. In this paper, authors use proof trees, building for every branch a concrete dispute tree which represents a sequence of alternating attacks by the opponent and counter-attacks by the proponent, defining a *backward argument* as a proof tree which can be seen as a top-down method of deduction, from the root (conclusion) to the terminal nodes (assumptions). The authors in [43], illustrate how their backward arguments are a generalization of SLD resolution, which is the basis of proof procedures for classical logic programming. This approach for building top-down proof-tree arguments is also considered in [126], where different approaches of *answer set justifications* are introduced. Furthermore, Apt *et.al.* characterize a deduction model from a logic program in two ways: 1) *backward-chaining*, based on a recursive, "top-down" chaining; and 2) *forward-chaining*, based on an inductive, "bottom-up" chaining [8]. The *backward argument* defined by Dung *et.al.* in [43] follows the Apt' backward-chaining procedure. In this setting, Paper II follows a different line than Dung *et.al.* in [43] and in some approaches of Argumentation (ABA) [22, 44] such as [126].

In [148], semantic equivalences between argumentation frameworks and logic programs are presented. The argument structure considered in Wu's work [148] and [28] is interesting to analyse because such process has relation with the semantic approach in Paper II. For example, given a logic program P an argument for Wu *et.al.* is a finite tree of rules from P such that: 1) each node (of the form $c \leftarrow a_1, \ldots, a_n, \; not\ b_1, \ldots, \; not\ b_m$) has exactly n children, each having a different head $a \in \{a_1, \ldots, a_n\}$ and 2) no rule occurs more than once in any root-originated branch of the tree. The conclusion of A is the head of its root. This approach establishes a tree structure of clauses starting from a *root* (the conclusion), removing those clauses which generate infinite loops. It is easy to see that by removing cycles through literals, the structure of an argument support in [148] is a stratified program.

There is a major difference in the argument notion among approaches building tree-like proof procedures (like [43, 8, 148, 113] among others) and the answer set programming approach: the construction of arguments proposed in Paper II follows a semantic interpretation of the argument support to find a stratified program. In this setting, it is worth differentiate between a *proof-oriented* argument construction and a *semantic-oriented* approach. In the first one, as in ABA, *syntactic* methods close to SLD resolution are used. In these approaches there are no semantic restrictions in the argument support, allowing arguments, for instance, of the form: $\langle \{f \leftarrow not\ f\}, \; f \rangle$ as in [148]. One can see that $\langle \{f \leftarrow not\ f\}, \; f \rangle$ is a self-attacked argument. The main contribution in Paper II avoids this type of arguments. It is also worth mentioning that WFS is empty and Stable semantics is undefined with the program $f \leftarrow not\ f$. In general, the answer set programming approach avoids self-attacked arguments. However, some coincidences in the argumentation building process between Dung's [43], Wu and Caminada's [148], and the answer set semantic method in Paper II, can be identified when stratified programs are considered. Despite these coincidences, the inference of stable and grounded extensions presented in [43] differs from the answer set semantic approach in the treatment of non-stratified programs.

5.2.2 Defeasible Explanations of Complex Activities

In this section, the notion of *hypothetical fragment* introduced in Paper I is analysed.

In the Dung's seminal paper on *abstract argumentation* [42], arguments are evaluated in an abstract level by taking only their inter-relationships into account, in this sense the internal nature of an abstract argument and the building method for create arguments are disregarded. In Paper II the internal structure of an arguments is investigated in order to generate consistent and well-formed support structures. The answer set programming approach for building arguments evaluates semantically the support of an argument in order to evaluate its consistency. This defeasible argumentation model was extended in Papers I, III and V, where the internal knowledge representation structure of arguments follows an activity-centric model. A number of defeasible argumentation models using logic programming have been proposed such as [53, 115] among others, but some of them do not fulfil well-known quality criteria [27, 45].

For example, in Paper I and III, an *activity framework* was introduced which is a knowledge structure following an activity-centric approach. The notion of hypothetical fragment of an activity follows a bottom-up approach providing consistent explanations (Figure 12). A key notion of a hypothetical fragment is regarded to the nature of an action, in Activity Theory actions are considered meaningful and oriented to a goal. A hypothetical fragment considers an action and the set of dependent sub-actions directed to sub-goals. The notion of sub-fragment in Paper III, as a structure supporting other fragments defines an implicit notion of an action set directed to the achievement of a main goal. A hypothetical fragment as a knowledge representation provides a quantifiable approach for providing explanations of different elements of the world.

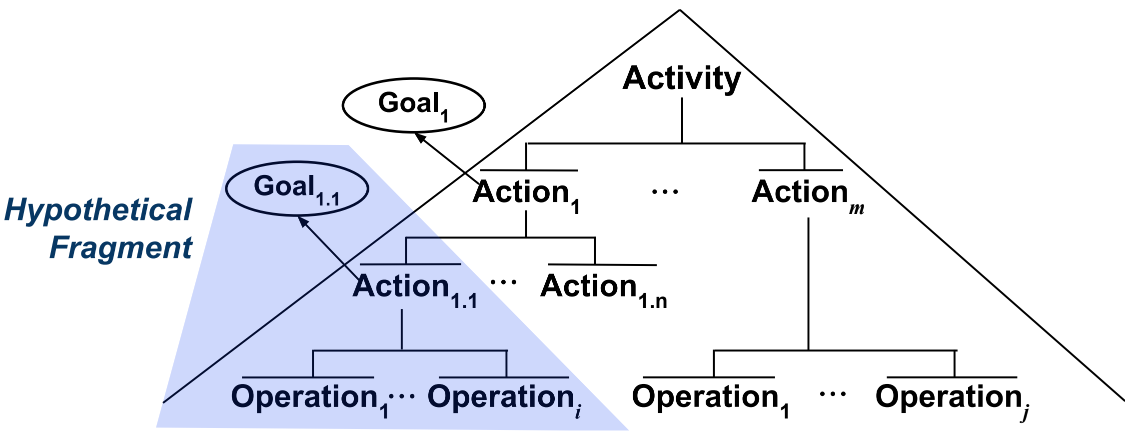


Figure 12: Hypothetical fragment of an activity.

In Paper V, an agent takes decisions considering different goals of an individual. The importance of structured hypothetical fragments under Activity Theory perspective is the acknowledge of a meaningful action, disregarding actions sets which are not related to the achievement of the target goal. In decision-making processes involving hypothetical fragments such as in Paper V, the "strongest" fragment carries a twofold *defeasibility*, one is given by the incomplete knowledge of the observations and the second one, is given by the uncertainty of the human action. This is an important characteristic of the argument-based explanations of complex activities proposed in this research.

5.3 Evaluation of Complex Activities

In the healthcare literature, evaluations of physical activity based on information obtained through sensors are accepted as valid evidence [3, 21, 132, 133, 134, 135]. In these computer-based system approaches, the evidence is linked to the confidence of the captured observations. Some characteristics of these systems have been identified:

- One source of data: in different approaches the data collection procedure is performed by using only one sensor monitor [3, 9, 20, 21, 52, 97]. Other evaluations use "parallel" methods for collecting evidence, such as videotaping or other sensor approaches with no coordination or interaction between the sources [4, 131, 137]

- Scalability: most of the sensor-based approaches are specifically used for measuring only one type of physical activity or physical phenomena, *e.g.*, [3, 9, 21, 25, 26, 68].

- Reactive systems: most of the approaches use a *reactive* approach, obtaining data from sensors and send it or storing it for *manual* inference.

In AI, the aforementioned approaches are defined as *reactive* systems [123], and they have substantial differences between an agent-based system platform for instance, measuring elements of a complex activity using the Capacity and Performance qualifiers introduced in Paper III.

Performance and Capacity values were calculated in a structured assessment tool which was considered as a complex activity in Paper III. Moreover, a pilot study was performed to exemplify the qualifiers notion using the Short Physical Performance Battery (SPPB) test [61].

The main impact of Paper III is the flexibility of the notion of qualifier using structured arguments, such as the hypothetical fragments introduced in Paper I. Qualifiers as a method for evaluating activities has different strengths compared to other approaches [3, 9, 20, 21, 52, 97]:

- Abstraction: Capacity and Performance qualifiers were obtained by considering two elements in structured arguments: observations and goals. The notion of qualifier can be extended to measure different elements in a complex activity, using argument-based approaches to calculate them.

- Data observation combination: the answer set programming method for building arguments allows to fuse different knowledge bases, inferring only information relevant to a specific part of a program (a complex activity captured by a program).

- Scalability: most of the sensor-based approaches are specifically used for measuring only one type of activity, *e.g.*, [3, 9, 21]. The approach presented in Paper III can be instantiated to measure any kind of complex activity.

In Paper III, calculation of Performance and Capacity qualifiers provides an instantaneous quantification of what an individual does and how a specific task is being performed, using as a reference an observation-based tool assessment. An important contribution of qualifiers is the analysis of achievement during a period of time. In Paper III, a four-months pilot study using the SPPB with three data capturing sessions was performed. Qualifiers provided a measurement of change in the execution of goal-based tasks. As a tool for physicians, the argument-based qualifiers may have an important impact to evaluate the ability of an individual conducting a complex activity during the time. In Figure 13, a temporal comparison of the Performance values is presented showing change in the execution of the sit-to-stand test during three sessions protocol, the figure highlights values of an individual (Individual 4 in purple) showing an apparent increase in her/his ability to run the test. The results of Paper III test show that:

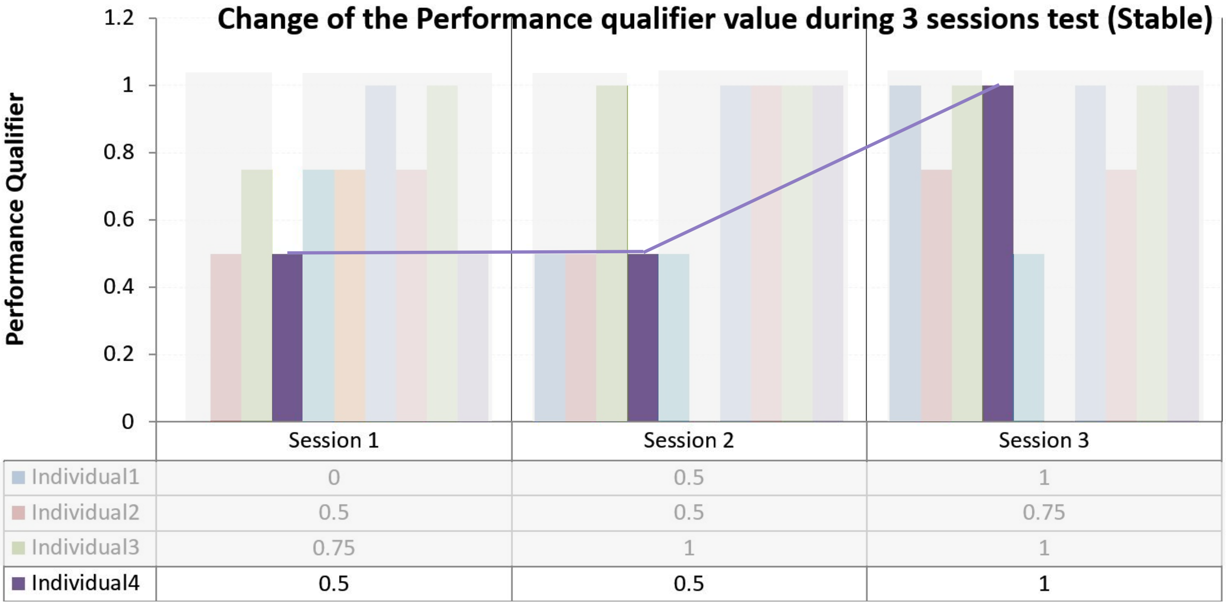


Figure 13: Performance value calculated during 3 months using stable semantics.

- The Capacity and Performance qualifiers can be defined in scenarios where observation-based and goal-based assessment tools are used supported by sensors. The SPPB as well as other structured tools [34, 56, 60, 62, 110, 121] is a test where sub-tasks evaluation has different perspective for judging an individual: 1) the achievement of each exercise and 2) the ability in the execution. This approach can capture and evaluate such structured assessment from both perspectives.
- There is a considerable difference between the values of the Performance and Capacity qualifiers when different argumentation semantics are considered. Given that the process of hypothesis argument selection can be performed by different semantics, the behaviour of the qualifiers evaluation follows also a more *skeptical* (in the case of Grounded) or a more *credulous* (in case of Stable, Preferred or Complete) evaluation of what an individual does and her/his ability to execute a task. In the evaluation of Performance qualifier Stable provides 65% more values than Grounded and in Capacity evaluation Stable gives 30% more.

Performance and Capacity evaluate different perspectives of an activity. The combined coding of Performance and Capacity is an interesting tool to understand the conduction of an activity in a given environment [106]. In Figure 14 a combined analysis of these two qualifiers is presented, using data from the test pilot of Paper III. This Performance vs. Capacity representation shows that a majority of the tested individuals have a low Capacity to execute correctly the chair standing of SPPB. On the other hand, the same figure shows that most of the individuals finished at least 50% of the five rising-up tasks.

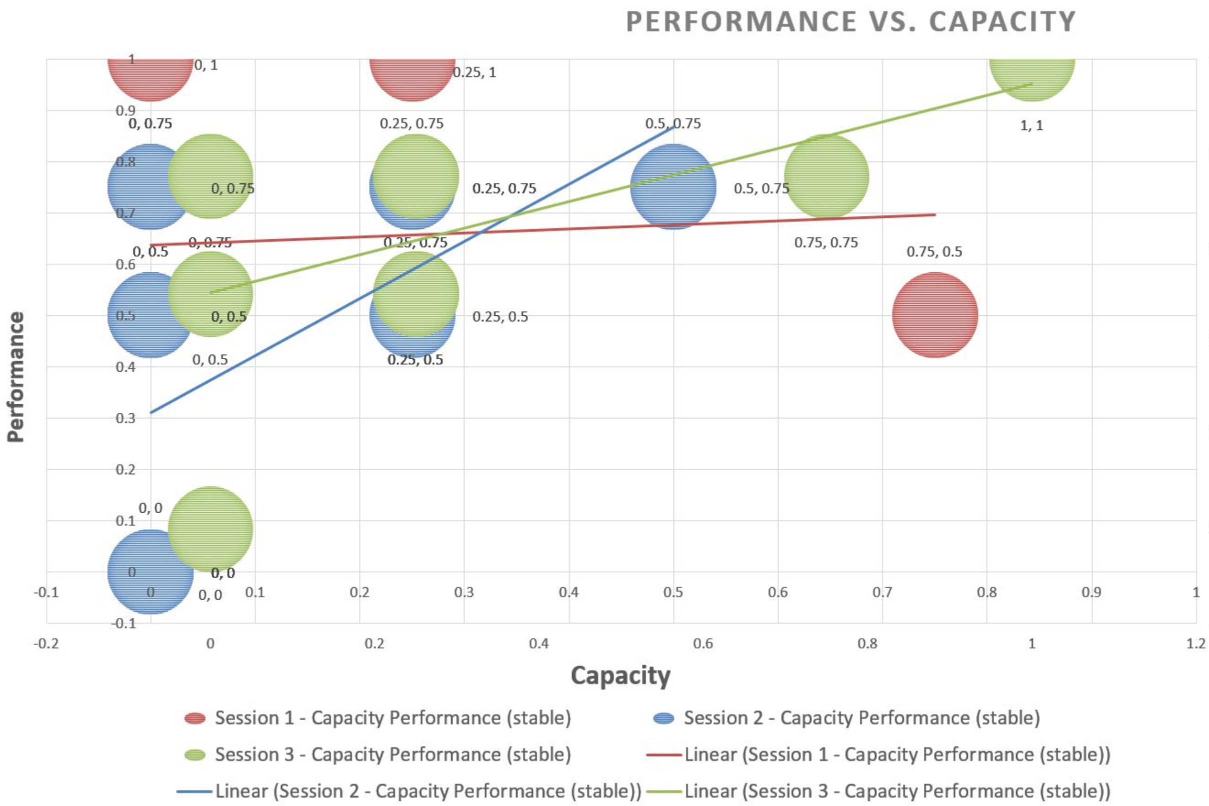


Figure 14: Performance vs. Capacity

5.4 Tailoring Assistive Services

Providing tailored support to individuals in their conduction of activities is a challenge, as mentioned in the introduction. As part of this research, the methods for representing and evaluating activity were supplemented with methods for selecting tailored responses to the individual. The assistive features were implemented in the technology developed in Papers III-IV. Agent-based approaches were applied that follow the information process in Figure 15.

The process depicted in Figure 15 involves the individual's goal preferences, context information about the agent's actions, following an activity-centered principle. The outcome of the decision-making process enables the delivery of tailored services, which were exemplify by sending messages to the individual in Paper IV-V. The main contribution of Paper IV was formative, paving the route for the development of different prototypes, as well as allowed identifying issues in the process of building and sending encouraging messages or positive feedback. Most of the issues of Paper IV, were corrected in Paper V by proposing a novel method for building pseudo-natural language sentences: the *activity-goal schemes*. The generation of messages uses structured arguments to link the activity being performed, the goal achieved (the conclusion of an argument) and an auxiliary text. In this setting, the generation message process relies on a consistent non-monotonic approach for building argument-based on explanations (Paper II), rather than in open-ended methods such as New Rhetoric or practical reasoning [30, 10, 57]. A limitation of the approach presented in Paper V is the lack of "naturalness" in the structure activity-goal-text, due to the activity scheme for building natural expressions.

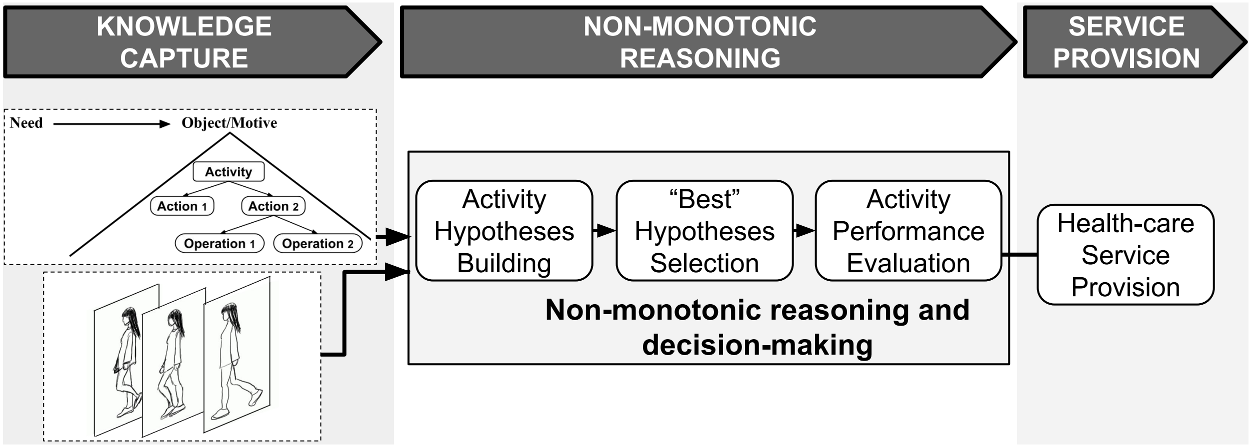


Figure 15: Tailored assistive systems based on an argumentation approach.

The generation of persuasive messages in ALI, presented in Paper V was inspired by scheme-based reasoning [143, 142, 63]. However, the persuasive messages generated have a different aim than *persuasion dialogues* in argumentation literature [18, 17, 142]. In [142], such differences are established, where persuasion is intended to persuade another individual to accept some contested proposition that s/he did not previously believe. In Paper V, the *persuadee* in principle agrees with and believes in the persuasion method used, which uses her/his own words and follows the idea of self-motivation.

Chapter 6

5. Future Work

There are several interesting extensions of the presented research in this thesis. Considering the first challenges addressed in this research relating to representing activities, the following are ongoing or included in future work:

- Formalize the activity dynamics, *i.e.,* investigating how the complex activity hierarchy changes over the time, particularly formalizing the so-called *automatization*, which is a transformation between actions and operations. Over the course of practice actions can become automatic operations [70]. If an agent detects this process, this information would be used for adapting the agent's behaviour.

- Analysis of temporal representations is essential when dealing with human activities. Activity dynamics is linked to the *span* of goals, *e.g.,* prepare the breakfast in the morning as a daily goal has a time span. The representation of time constraints in the agent's knowledge base will improve the timing for adapting the agents behaviour.

- Preferences among goals were explored without considering the motivations behind the execution of activities. Currently, multiple motivational factors that affects the performance of activities, which influence the individual's preferences are investigated.

The following research topics relating to reasoning and evaluating of activities are also focussed in future work:

- Identify relevant criteria for selecting argumentation semantics when structured arguments are considered. The "semantic" construction of arguments proposed in this research opens different perspectives to investigate "families" of semantics which allow the application of answer set programming to evaluate the support of arguments.

- Compare methods for building arguments/proofs in assumption-based argumentation (ABA) [22] and the proposed argument building under answer set programming.

Finally, the evaluation of different prototypes both experimentally and in realistic settings over a longer period of time is part of the future work:

- Integrate argumentation engine sensor-based system where inconsistency of observations of the world are captured by *Extended Logic Programs* (ELP). Furthermore, a quality comparison of the argument engine with other approaches is also interesting given the relevance of other answer-set solvers in practical applications.

- Different knowledge sources will be integrated for extending and improving the person-specific knowledge based on arguments. A pilot study will be conducted within the near future with older adults.

- Improve the human-agent dialogue methods for handling changes of preferences and for verifying the validity of arguments with respect to time. User studies will be conducted, which will involve more subjects and conducted during a longer test period. Allowing the use over a longer period of time will provide insight into how the application affects the user's decision-making and activity performance.

Bibliography

[1] Jake K Aggarwal and Quin Cai. Human motion analysis: A review. In *Nonrigid and Articulated Motion Workshop, 1997. Proceedings., IEEE*, pages 90–102. IEEE, 1997.

[2] Jake K Aggarwal and Michael S Ryoo. Human activity analysis: A review. *ACM Computing Surveys (CSUR)*, 43(3):16, 2011.

[3] Gustavo JM Almeida, Mary Chester M Wasko, Kwonho Jeong, Charity G Moore, and Sara R Piva. Physical activity measured by the sensewear armband in women with rheumatoid arthritis. *Physical therapy*, 91(9):1367–1376, 2011.

[4] K Aminian, Ph Robert, EE Buchser, B Rutschmann, D Hayoz, and M Depairon. Physical activity monitoring based on accelerometry: validation and comparison with video observation. *Medical & biological engineering & computing*, 37(3):304–308, 1999.

[5] M Amoretti, F Wientapper, and F Furfari. Sensor data fusion for activity monitoring in ambient assisted living environments. In *ICST 2010*, pages 206–221. Springer, Pisa, Italy, 2010.

[6] G Aldo Antonelli. Non-monotonic logic. *Stanford Encyclopedia of Philosophy*, 2006.

[7] Grigoris Antoniou, Michael J. Maher, and David Billington. Defeasible logic versus logic programming without negation as failure. *The Journal of Logic Programming*, 42(1):47–57, 2000.

[8] Krzysztof R Apt, Howard A Blair, and Adrian Walker. *Towards a theory of declarative knowledge*. IBM TJ Watson Research Center, 1986.

[9] Daniel Arvidsson, Frode Slinde, Sven Larsson, Lena Hulthen, et al. Energy cost of physical activities in children: validation of sensewear armband. *Medicine and science in sports and exercise*, 39(11):2076, 2007.

[10] Katie Atkinson, Trevor Bench-Capon, and Peter McBurney. Computational representation of practical argument. *Synthese*, 152(2):157–206, 2006.

[11] Aruna D. Balakrishnan, Tara Matthews, and Thomas P. Moran. Fitting an activity-centric system into an ecology of workplace tools. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '10, pages 787–790, New York, NY, USA, 2010. ACM.

[12] Chitta Baral. *Knowledge Representation, Reasoning and Declarative Problem Solving*. Cambridge University Press, 2003.

[13] Chitta Baral and Michael Gelfond. Logic programming and knowledge representation. *The Journal of Logic Programming*, 19:73–148, 1994.

[14] Pietro Baroni, Martin Caminada, and Massimiliano Giacomin. An introduction to argumentation semantics. *Knowledge Engineering Review*, 26(4):365–410, 2011.

[15] Gregory Bedny and Waldemar Karwowski. *A systemic-structural theory of activity: Applications to human performance and work design*. CRC Press, 2006.

[16] Trevor Bench-Capon, Paul Dunne, T.J.M. Bench-Capon, and Paul E. Dunne. Argumentation in artificial intelligence. *Artificial Intelligence*, 171(10):619–641, 2007.

[17] Trevor Bench-Capon and Henry Prakken. Argumentation. In *Information Technology and Lawyers*, pages 61–80. Springer Netherlands, 2006.

[18] Trevor JM Bench-Capon. Persuasion in practical argument using value-based argumentation frameworks. *Journal of Logic and Computation*, 13(3):429–448, 2003.

[19] Salem Benferhat, Didier Dubois, and Henri Prade. Some syntactic approaches to the handling of inconsistent knowledge bases: A comparative study part 1: The flat case. *Studia Logica*, 58(1):17–45, 1997.

[20] Kristie F Bjornson. Physical activity monitoring in children and youths. *Pediatric Physical Therapy*, 17(1):37–45, 2005.

[21] Kristie F Bjornson, Basia Belza, Deborah Kartin, Rebecca Logsdon, and John F McLaughlin. Ambulatory physical activity performance in youth with cerebral palsy and youth who are developing typically. *Physical Therapy*, 87(3):248–257, 2007.

[22] Andrei Bondarenko, Francesca Toni, and Robert A Kowalski. An assumption-based framework for non-monotonic reasoning. In *LPNMR*, volume 93, pages 171–189, 1993.

[23] Bruno Bouchard, Sylvain Giroux, and Abdenour Bouzouane. A keyhole plan recognition model for alzheimer's patients: first results. *Applied Artificial Intelligence*, 21(7):623–658, 2007.

[24] M. Bratman. *Intention, plans, and practical reason*. Harvard University Press, 1987.

[25] Monica Erika Busse, Owen R Pearson, R Van Deursen, and Charles Mark Wiles. Quantified measurement of activity provides insight into motor function and recovery in neurological disease. *Journal of Neurology, Neurosurgery & Psychiatry*, 75(6):884–888, 2004.

[26] MIGUEL A Calabró, Gregory J Welk, and Joey C Eisenmann. Validation of the sensewear pro armband algorithms in children. *Medicine and science in sports and exercise*, 41(9):1714–1720, 2009.

[27] Martin Caminada and Leila Amgoud. On the evaluation of argumentation formalisms. *Artificial Intelligence*, 171(5):286–310, 2007.

[28] Martin Caminada, Samy Sá, and João Alcântara. On the equivalence between logic programming semantics and argumentation semantics. In *Symbolic and Quantitative Approaches to Reasoning with Uncertainty*, pages 97–108. Springer, 2013.

[29] Sandra Carberry. Techniques for plan recognition. *User Modeling and User-Adapted Interaction*, 11(1-2):31–48, 2001.

[30] Berardina De Carolis, Fiorella de Rosis, Floriana Grasso, Anna Rossiello, Dianne C. Berry, and Tony Gillie. Generating recipient-centered explanations about drug prescription. *Artificial Intelligence in Medicine*, 8(2):123 – 145, 1996.

[31] John M Carroll. Human–computer interaction. *Encyclopedia of Cognitive Science*, 2009.

[32] Carl J Caspersen, Kenneth E Powell, and Gregory M Christenson. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public health reports*, 100(2):126, 1985.

[33] Philip R Cohen, C Raymond Perrault, and James F Allen. Beyond question answering. *Strategies for natural language processing*, pages 245–274, 1981.

[34] M Elaine Cress, David M Buchner, Kent A Questad, Peter C Esselman, Robert S Schwartz, et al. Continuous-scale physical functional performance in healthy older adults: a validation study. *Archives of physical medicine and rehabilitation*, 77(12):1243–1250, 1996.

[35] Stina DahlstrÃ¶m and Cilla Remmets. Balance test with mobile phone, how does it work in practice? a pilot study (in swedish). B.S. Thesis, Umeå University, Physiotherapy Department, 2014. to appear.

[36] Ernest Davis. Pouring liquids: A study in commonsense physical reasoning. *Artificial Intelligence*, 172(12):1540–1578, 2008.

[37] Yannis Dimopoulos and Antonis C Kakas. Logic programming without negation as failure. In *ILPS*, pages 369–383, 1995.

[38] Jürgen Dix. A classification theory of semantics of normal logic programs: I. strong properties. *Fundamenta Informaticae*, 22(3):227–255, 1995.

[39] Jürgen Dix. A classification theory of semantics of normal logic programs: II. weak properties. *Fundamenta Informaticae*, 22(3):257–288, 1995.

[40] Jürgen Dix and Martin Müller. Partial evaluation and relevance for approximations of the stable semantics. In *Methodologies for Intelligent Systems*, pages 511–520. Springer, 1994.

[41] Didier Dubois, Petr Hájek, and Henri Prade. Knowledge-driven versus data-driven logics. *Journal of logic, Language and information*, 9(1):65–89, 2000.

[42] Phan Minh Dung. On the acceptability of arguments and its fundamental role in non-monotonic reasoning, logic programming and n-person games. *Artificial Intelligence*, 77(2):321–357, September 1995.

[43] Phan Minh Dung, Robert A Kowalski, and Francesca Toni. Dialectic proof procedures for assumption-based, admissible argumentation. *Artificial Intelligence*, 170(2):114–159, 2006.

[44] Phan Minh Dung, Robert A Kowalski, and Francesca Toni. Assumption-based argumentation. In *Argumentation in Artificial Intelligence*, pages 199–218. Springer, 2009.

[45] Phan Minh Dung and Phan Minh Thang. Closure and consistency in logic-associated argumentation. *Journal of Artificial Intelligence Research*, 49:79–109, 2014.

[46] Vasiliki Efstathiou and Anthony Hunter. Algorithms for effective argumentation in classical propositional logic: A connection graph approach. In *Foundations of Information and Knowledge Systems*, pages 272–290. Springer, 2008.

[47] Y. Engeström, R. Miettinen, and R.L. Punamäki. Activity theory and individual and social transformation. In *Perspectives on Activity Theory*, Learning in Doing: Social, Cognitive and Computational Perspectives, pages 19–38. Cambridge University Press, 1999.

[48] Y. Engeström, R. Miettinen, and R.L. Punamäki. *Perspectives on Activity Theory*. Learning in Doing: Social, Cognitive and Computational Perspectives. Cambridge University Press, 1999.

[49] Yrjö Engeström. Learning by expanding: An activity-theoretical approach to developmental research. 1987.

[50] A.L. Fawcett. *Principles of Assessment and Outcome Measurement for Occupational Therapists and Physiotherapists: Theory, Skills and Application*. Wiley, 2013.

[51] Chrysi Filippaki, Grigoris Antoniou, and Ioannis Tsamardinos. Using Constraint Optimizationfor Conflict Resolution and Detail Control in Activity Recognition. In *AmI 2011*, pages 51 – 60. Springer, 2011.

[52] George D Fulk, Stephanie A Combs, Kelly A Danks, Coby D Nirider, Bhavana Raja, and Darcy S Reisman. Accuracy of 2 activity monitors in detecting steps in people with stroke and traumatic brain injury. *Physical therapy*, 94(2):222–229, 2014.

[53] Alejandro J García and Guillermo R Simari. Defeasible logic programming: An argumentative approach. *Theory and practice of logic programming*, 4(1+ 2):95–138, 2004.

[54] Michael Gelfond and Vladimir Lifschitz. The Stable Model Semantics for Logic Programming. In R. Kowalski and K. Bowen, editors, *5th Conference on Logic Programming*, pages 1070–1080. MIT Press, 1988.

[55] Michael Gelfond and Vladimir Lifschitz. Classical negation in logic programs and disjunctive databases. *New Generation Computing*, 9(3-4):365–385, 1991.

[56] Meghan B Gerety, Cynthia D Mulrow, Michael R Tuley, Helen P Hazuda, Michael J Lichtenstein, Richard Bohannon, Deanna N Kanten, Margaret B O'Neil, and Ann Gorton. Development and validation of a physical performance instrument for the

functionally impaired elderly: the physical disability index (pdi). *Journal of gerontology*, 48(2):M33–M38, 1993.

[57] Floriana Grasso, Alison Cawsey, and Ray Jones. Dialectical argumentation to solve conflicts in advice giving: a case study in the promotion of healthy nutrition. *International Journal of Human-Computer Studies*, 53(6):1077–1115, 2000.

[58] E. Guerrero, H. Lindgren, and J.C. Nieves. Strata, a platform for evaluating physical capacity based on triangulation of multiple observation sources. In *13th Workshop on Intelligent Environments Supporting Health and Wellbeing. In 13th Scandinavian Conference on Artificial Intelligence (SCAI 2016)*, 2016.

[59] E. Guerrero, J.C. Nieves, M. Sandlund, and H Lindgren. Activity Qualifiers in an Argumentation Framework as Instruments for Agents When Evaluating Human Activity. In Y. Demazeau et al., editor, *Advances in Practical Applications of Scalable Multiagent Systems. The PAAMS Collection*, chapter 1, pages 1 – 12. Springer International Publishing Switzerland, 2016.

[60] Jack M Guralnik, Laurence G Branch, Steven R Cummings, and J David Curb. Physical performance measures in aging research. *Journal of Gerontology*, 44(5):M141–M146, 1989.

[61] Jack M Guralnik, Eleanor M Simonsick, Luigi Ferrucci, Robert J Glynn, Lisa F Berkman, Dan G Blazer, Paul A Scherr, and Robert B Wallace. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *Journal of Gerontology*, 49(2):M85–M94, 1994.

[62] Stephen M Haley, Larry H Ludlow, Bruce M Gans, Ruth M Faas, and Constance A Inacio. Tufts assessment of motor performance: an empirical approach to identifying motor performance categories. *Arch Phys Med Rehabil*, 72(6):359–66, 1991.

[63] A.C. Hastings. *A Reformulation of the Modes of Reasoning in Argumentation*. Northwestern University, 1962.

[64] Hossein Mousavi Hondori, Maryam Khademi, and Cristina V Lopes. Monitoring intake gestures using sensor fusion (microsoft kinect and inertial sensors) for smart home telerehab setting. In *2012 1st Annual IEEE Healthcare Innovation Conference*, 2012.

[65] Somboon Hongeng, Francois Brémond, and Ramakant Nevatia. Representation and optimal recognition of human activities. In *Computer Vision and Pattern Recognition, 2000. Proceedings. IEEE Conference on*, volume 1, pages 818–825. IEEE, 2000.

[66] Steven Houben, Morten Esbensen, and Jakob Bardram. A situated model and architecture for distributed activity-based computing. *Proc. of MODIQUITOUS*, 12:9–13, 2012.

[67] Faraja Teddy Igira and Judith Gregory. Cultural historical activity theory. *Handbook of research on contemporary theoretical models in information systems*, pages 434–454, 2009.

[68] John M Jakicic, Marsha Marcus, Kara I Gallagher, COLBY Randall, Erin Thomas, Fredric L Goss, and Robert J Robertson. Evaluation of the sensewear pro armband to assess energy expenditure during exercise. *Medicine and science in sports and exercise*, 36(5):897–904, 2004.

[69] Antonis C. Kakas, Robert A. Kowalski, and Francesca Toni. Abductive logic programming. *Journal of Logic and Computation*, 2(6):719–770, 1992.

[70] Victor Kaptelinin and Bonnie Nardi. *Acting with Technology: Activity Theory and Interaction Design*. Acting with Technology. MIT Press, 2006.

[71] Victor Kaptelinin and Bonnie A Nardi. Activity theory: Basic concepts and applications. In *CHI'97 Extended Abstracts on Human Factors in Computing Systems*, pages 158–159. ACM, 1997.

[72] Henry A. Kautz. Reasoning about plans. chapter A Formal Theory of Plan Recognition and Its Implementation, pages 69–124. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1991.

[73] Henry A Kautz and James F Allen. Generalized plan recognition. In *AAAI*, volume 86, page 5, 1986.

[74] Eunju Kim and Sumi Helal. Revisiting human activity frameworks. In *ICST Conf., S-Cube 2010*, pages 219 – 234, Miami, FL, USA, 2010. Springer.

[75] Volker Krüger, Danica Kragic, Aleš Ude, and Christopher Geib. The meaning of action: a review on action recognition and mapping. *Advanced Robotics*, 21(13):1473–1501, 2007.

[76] Nicholas Kushmerick, Tessa Lau, Mark Dredze, and Rinat Khoussainov. Activity-centric email: A machine learning approach. In *PROCEEDINGS OF THE NATIONAL CONFERENCE ON ARTIFICIAL INTELLIGENCE*, volume 21, page 1634. Menlo Park, CA; Cambridge, MA; London; AAAI Press; MIT Press; 1999, 2006.

[77] Kari Kuutti. Activity theory as a potential framework for human-computer interaction research. *Context and consciousness: Activity theory and human-computer interaction*, pages 17–44, 1996.

[78] NY Leenders, W Michael Sherman, HN Nagaraja, and C Lawrence Kien. Evaluation of methods to assess physical activity in free-living conditions. *Medicine and science in sports and exercise*, 33(7):1233–1240, 2001.

[79] Aleksi Nikolaevich Leontiev. *Activity, consciousness, and personality.* Prentice-Hall, Englewood Cliffs, N.J., 1978.

[80] Aleksei Nikolaevich Leontyev. Activity and consciousness. *Moscow: Personality*, 1974.

[81] Vladimir Lifschitz. Foundations of logic programming. *Principles of Knowledge Representation*, 3:69–127, 1996.

[82] Vladimir Lifschitz. What is answer set programming?. In *AAAI*, volume 8, pages 1594–1597, 2008.

[83] Vladimir Lifschitz, Leora Morgenstern, and David Plaisted. Knowledge representation and classical logic. *Handbook of Knowledge Representation*, 1:3–88, 2008.

[84] Vladimir Lifschitz and Alexander Razborov. Why are there so many loop formulas? *ACM Trans. Comput. Logic*, 7(2):261–268, April 2006.

[85] Helena Lindgren. Activity-theoretical model as a tool for clinical decision-support development. In *15th International Conferenceon KnowledgeEngineeringand KnowledgeManagement, Poster and demo proceedings in EKAW*, volume 215, pages 23–25, 2006.

[86] Helena Lindgren and Ingeborg Nilsson. Towards user–authored agent dialogues for assessment in personalised ambient assisted living. *International Journal of Web Engineering and Technology*, 8(2):154–176, 2013.

[87] Helena Lindgren and Ingeborg Nilsson. Towards user-authored agent dialogues for assessment in personalised ambient assisted living. *International Journal of Web Engineering and Technology*, page in press, 2013.

[88] Helena Lindgren and Chunli Yan. ACKTUS: A platform for developing personalized support systems in the health domain. In *Proceedings of the 5th International Conference on Digital Health 2015*, DH '15, pages 135–142, New York, NY, USA, 2015. ACM.

[89] Ye Liu, Liqiang Nie, Li Liu, and David S Rosenblum. From action to activity: Sensor-based activity recognition. *Neurocomputing*, 2015.

[90] Jorge Lobo, Jack Minker, and Arcot Rajasekar. *Foundations of disjunctive logic programming.* The MIT Press, 1992.

[91] Luca Longo and Lucy Hederman. Argumentation theory for decision support in health-care: a comparison with machine learning. In *Brain and Health Informatics*, pages 168–180. Springer, 2013.

[92] John McCarthy. *Programs with common sense.* Defense Technical Information Center, 1963.

[93] John McCarthy. Circumscription: a form of non-monotonic reasoning. *Artificial Intelligence*, 13(1):27–39, 1980.

[94] John McCarthy and Patrick Hayes. *Some philosophical problems from the standpoint of artificial intelligence.* Stanford University USA, 1968.

[95] John McCarthy and Patrick J Hayes. Some philosophical problems from the standpoint of artificial intelligence. *Readings in artificial intelligence*, pages 431–450, 1969.

[96] Drew McDermott. Nonmonotonic logic II: Nonmonotonic modal theories. *Journal of the ACM (JACM)*, 29(1):33–57, 1982.

[97] Craig M McDonald, Lana Widman, R Ted Abresch, Sandra A Walsh, and Denise D Walsh. Utility of a step activity monitor for the measurement of daily ambulatory activity in children. *Archives of physical medicine and rehabilitation*, 86(4):793–801, 2005.

[98] Jack Minker. On indefinite databases and the closed world assumption. In *6th Conference on Automated Deduction*, pages 292–308. Springer, 1982.

[99] Marvin Minsky. A framework for representing knowledge. 1974.

[100] Robert C Moore. Semantical considerations on nonmonotonic logic. *Artificial Intelligence*, 25(1):75–94, 1985.

[101] Boris Motik, Ian Horrocks, Riccardo Rosati, and Ulrike Sattler. Can owl and logic programming live together happily ever after? In *The Semantic Web-Iswc 2006*, pages 501–514. Springer, 2006.

[102] Juan Carlos Nieves and Roberto Confalonieri. A Possibilistic Argumentation Decision Making Framework with Default Reasoning. In *Fundamenta Informaticae 113*, volume 113, pages 41–61, 2011.

[103] Donald Nute. Defeasible logic. In *Handbook of logic in artificial intelligence and logic programming*. Citeseer, 1994.

[104] Donald Nute. Defeasible logic. In *Web Knowledge Management and Decision Support*, pages 151–169. Springer, 2003.

[105] World Health Organization. The international classification of functioning, disability and health (icf).

[106] World Health Organization. *How to use the ICF: A practical manual for using the International Classification of Functioning, Disability and Health (ICF)*. WHO, 2013.

[107] L. Padgham and M. Winikoff. *Developing Intelligent Agent Systems: A Practical Guide*. Wiley Series in Agent Technology. Wiley, 2005.

[108] David B Peterson. International classification of functioning, disability and health: An introduction for rehabilitation psychologists. *Rehabilitation Psychology*, 50(2):105, 2005.

[109] Jean Piaget. The origins of intelligence in children. *Journal of Consulting Psychology*, 17(6):467, 1953.

[110] Diane Podsiadlo and Sandra Richardson. The timed" up & go": a test of basic functional mobility for frail elderly persons. *Journal of the American geriatrics Society*, 39(2):142–148, 1991.

[111] Helene J Polatajko, Angela Mandich, and Rose Martini. Dynamic performance analysis: A framework for understanding occupational performance. *American Journal of Occupational Therapy*, 54(1):65–72, 2000.

[112] John L Pollock. Defeasible reasoning. *Cognitive Science*, 11(4):481–518, 1987.

[113] Henry Prakken. An abstract framework for argumentation with structured arguments. *Argument and Computation*, 1(2):93–124, 2010.

[114] Henry Prakken. Some reflections on two current trends in formal argumentation. In *Logic Programs, Norms and Action*, pages 249–272. Springer, 2012.

[115] Henry Prakken and Giovanni Sartor. Argument-based extended logic programming with defeasible priorities. *Journal of applied non-classical logics*, 7(1-2):25–75, 1997.

[116] Teodor C. Przymusinski. Every logic program has a natural stratification and an iterated least fixed point model (extended abstract). pages 11–21. ACM Press, 1989.

[117] Iyad Rahwan. Guest editorial: Argumentation in multi-agent systems. *Autonomous Agents and Multi-Agent Systems*, 11(2):115–125, 2005.

[118] Anand S Rao, Michael P Georgeff, et al. Bdi agents: From theory to practice. In *ICMAS*, volume 95, pages 312–319, 1995.

[119] Raymond Reiter. *On closed world data bases*. Springer, 1978.

[120] Raymond Reiter. A logic for default reasoning. *Artificial Intelligence*, 13(1):81–132, 1980.

[121] David B Reuben and Albert L Siu. An objective measure of physical function of elderly outpatients. *J Am Geriatr Soc*, 38(10):1105–12, 1990.

[122] Glyn C Roberts, Darren C Treasure, and David E Conroy. Understanding the dynamics of motivation in sport and physical activity: An achievement goal interpretation. *Handbook of Sport Psychology, Third Edition*, pages 1–30, 2007.

[123] Stuart Russell and Peter Norvig. *Artificial intelligence: a modern approach*. Prentice Hall, third edit edition, 2010.

[124] Stuart Jonathan Russell, Peter Norvig, John F Canny, Jitendra M Malik, and Douglas D Edwards. *Artificial intelligence: a modern approach*, volume 2. Prentice Hall Englewood Cliffs, 1995.

[125] David L Sackett, William MC Rosenberg, JA Muir Gray, R Brian Haynes, and W Scott Richardson. Evidence based medicine: what it is and what it isn't. *Bmj*, 312(7023):71–72, 1996.

[126] Claudia Schulz and Francesca Toni. Justifying answer sets using argumentation. *Theory and Practice of Logic Programming*, 16(01):59–110, 2016.

[127] Murray Shanahan. *Solving the frame problem: a mathematical investigation of the common sense law of inertia*. MIT press, 1997.

[128] Marianne Silfverskiöld. Development and validation of an application for mobile phone with a self-test of standing up from a chair (in swedish). M.Sc. Thesis, Umeå University, Physiotherapy Department, 2014. to appear.

[129] Martyn Standage, Joan L Duda, and Nikos Ntoumanis. A model of contextual motivation in physical education: Using constructs from self-determination and achievement goal theories to predict physical activity intentions. *Journal of educational psychology*, 95(1):97, 2003.

[130] Umberto Straccia. *Reasoning Web: 4th International Summer School 2008, Venice, Italy, September 7-11, 2008, Tutorial Lectures*, chapter Managing Uncertainty and Vagueness in Description Logics, Logic Programs and Description Logic Programs, pages 54–103. Springer Berlin Heidelberg, Berlin, Heidelberg, 2008.

[131] Kristin Taraldsen, Torunn Askim, Olav Sletvold, Elin Kristin Einarsen, Karianne Grüner Bjåstad, Bent Indredavik, and Jorunn Laegdheim Helbostad. Evaluation of a body-worn sensor system to measure physical activity in older people with impaired function. *Physical therapy*, 91(2):277–285, 2011.

[132] Stewart G Trost, LM Kerr, Dianne S Ward, and Russell R Pate. Physical activity and determinants of physical activity in obese and non-obese children. *International journal of obesity and related metabolic disorders: journal of the International Association for the Study of Obesity*, 25(6):822–829, 2001.

[133] Stewart G Trost, Russell R Pate, James F Sallis, Patty S Freedson, Wendell C Taylor, Marsha Dowda, and John Sirard. Age and gender differences in objectively measured physical activity in youth. *Medicine and science in sports and exercise*, 34(2):350–355, 2002.

[134] Catrine Tudor-Locke, Robert P Pangrazi, Charles B Corbin, William J Rutherford, Susan D Vincent, Anders Raustorp, L Michaud Tomson, and Thomas F Cuddihy. Bmi-referenced standards for recommended pedometer-determined steps/day in children. *Preventive medicine*, 38(6):857–864, 2004.

[135] Catrine E Tudor-Locke and Anita M Myers. Challenges and opportunities for measuring physical activity in sedentary adults. *Sports Medicine*, 31(2):91–100, 2001.

[136] Pavan Turaga, Rama Chellappa, Venkatramana S Subrahmanian, and Octavian Udrea. Machine recognition of human activities: A survey. *Circuits and Systems for Video Technology, IEEE Transactions on*, 18(11):1473–1488, 2008.

[137] M Uiterwaal, EBC Glerum, HJ Busser, and RC Van Lummel. Ambulatory monitoring of physical activity in working situations, a validation study. *Journal of medical engineering & technology*, 22(4):168–172, 1998.

[138] Robert J Vallerand. Intrinsic and extrinsic motivation in sport and physical activity. *Handbook of sport psychology*, 3:59–83, 2007.

[139] Allen Van Gelder. Negation as failure using tight derivations for general logic programs. *The Journal of Logic Programming*, 6(1-2):109–133, 1989.

[140] Allen Van Gelder, Kenneth Ross, and John S Schlipf. Unfounded sets and well-founded semantics for general logic programs. In *Proceedings of the seventh ACM SIGACT-SIGMOD-SIGART symposium on Principles of database systems*, pages 221–230. ACM, 1988.

[141] Gerard AW Vreeswijk. Abstract argumentation systems. *Artificial intelligence*, 90(1):225–279, 1997.

[142] Douglas Walton, Christopher Reed, and Fabrizio Macagno. *Argumentation schemes*. Cambridge University Press, 2008.

[143] Douglas N Walton. *Argumentation schemes for presumptive reasoning*. Psychology Press, 1996.

[144] Mark Weiser. The computer for the 21st century. *Scientific American*, 265(3):94–104, 1991.

[145] K. Wolfgang. *The Mentality of Apes*. Routledge, 2013.

[146] M. Wooldridge. *An Introduction to MultiAgent Systems*. Wiley, 2009.

[147] Michael Wooldridge, Nicholas R Jennings, et al. Intelligent agents: Theory and practice. *Knowledge engineering review*, 10(2):115–152, 1995.

[148] Yining Wu, Martin Caminada, and Dov M Gabbay. Complete extensions in argumentation coincide with 3-valued stable models in logic programming. *Studia logica*, 93(2-3):383–403, 2009.

[149] Lotfi Asker Zadeh. Fuzzy sets as a basis for a theory of possibility. *Fuzzy sets and systems*, 1(1):3–28, 1978.