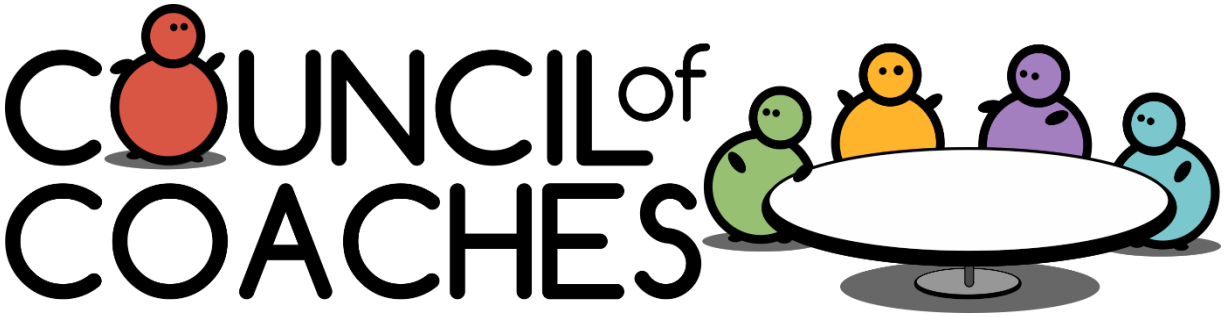

D3.1: Initial knowledge base design and coaching strategies

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Abstract

The Council of Coaches project develops a council of multiple embodied conversational coaches to provide tailored coaching on various domains. Each of these coaches will have their own coaching domain (for example, diet, cognition or physical exercise). A user of the Council of Coaches system will interact with several coaches at once.

In this deliverable, we will deliver an initial design for the coaches' coaching strategies and their shared knowledge base. First, we will describe the design process for the coaching strategies in which we take into account the literature on behavioural change and the influence of context. This can be observed in Section 3. We will then continue with the initial design of the knowledge base, which will make up Section 4.

Corrections

v1.0.1	Correctly applied EU logo on header page.
	Changed UPMC to Sorbonne University (SU).

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Symbols, abbreviations and acronyms

AAF	Abstract Argumentation Frameworks
ACT	Acceptance and Commitment Therapy
Ad	Adaptation
AIF (db)	Argument Interchange Format (database)
APML	Affective Presentation Markup Language
BCTT	Behavior Change Technique Taxonomy
BML	Behavior Markup Language
BS	Behaviour Set
CA	Context Awareness
CBT	Cognitive Behaviour Therapy
CHE	Context History Entrepot
CMC	Centre for Monitoring and Coaching
CMNA	Computational Models of Natural Argument
COUCH	Council of Coaches
CycL	Cyc artificial intelligence project Language
D	Deliverable
DAML	Darpa Agent Markup Language
DBT	Danish Board of Technology Foundation
DSME	Diabetes self-management education
EC	European Commission
ECA	Embodied Conversational Agent
ECC	Embodied Conversational Coach
FB	Feedback
FML	Function Markup Language
FTA	Face-Threatening Acts
GPS	Global Positioning System
GS	Goal Setting
GSR	Galvanic Skin Response
GUMO	General User Model Ontology
HAPA	Health Action Process Approach
HBAF	Holistic Behaviour Analysis Framework
HCI	Human-Computer Interaction
IHI	Inter-Human Interaction

IRI	Internationalized Resource Identifier
ISPRINT	Innovation Sprint
JSON	JavaScript Object Notation
M	Month
MM	Motivational Messages
MS	Milestone
OIL	Ontology Inference Layer
OWL	Web Ontology Language
PSD	Persuasive Systems Design
RDF	Resource Description Framework
RDFS	Resource Description Framework Schema
RRD	Roessingh Research and Development
SAIBA	Situation, Agent, Intention, Behaviour, Animation
SCT	Social Cognitive Theory
SPARQL	SPARQL Protocol and RDF Query Language
SL	Self learning
STD	Self-determination Theory
UDun	University of Dundee
UPMC	Université Pierre et Marie Curie, Paris 6
UPV	Universitat Politècnica de València
URI	Uniform Resource Identifier
UT	University of Twente
UT	User Targeting
WP	Work Package
XML	Extensible Markup Language

Glossary

We provide below a short glossary of terms used throughout this deliverable – and their attributed meaning as used in this document. The project is in the process of aligning the use of terminology across the various technical work packages. Some inconsistencies in use of terminology between this deliverable D3.1 and the technical deliverables written in the same time period (D4.1, D5.1 and D6.1) may occur, and may cause these definitions to be refined.

Coach – An entity that interacts with a person and in doing so applies coaching strategies. Can be human or software-based.

Embodied Conversational Agent (ECA) – A virtual or robotic human-like character that demonstrates many of the same properties as humans in face-to-face conversation, including the ability to produce and respond to verbal and nonverbal communication.

Embodied Conversational Coach (ECC) – An embodied conversational agent that takes on the role of a coach.

Context – That which surrounds a focal event.

When discussing coaching strategies: The situation in which coaching is applied. This involves aspects of the environment in which the user is situated. Examples include the weather, social situation, and location.

When discussing knowledge bases: The aspects surrounding the topic that is being reasoned about. Differences in context can also mean differences in the level of detail or assumptions that are required to be modelled.

Situation – A combination of a context and a user. That is, the elements present in the context in combination with the user's features and state make for the situation.

User State – Divisible into a user's internal state and a user's physical state.

A user's internal state refers to the processes that go on within a person (for example, in terms of beliefs, motivations, etc.), which can only be measured indirectly.

A user's physical state refers to the observations that can be made about the user objectively (for example, activity through step counts)

Knowledge Base – A software component that stores facts and rules related to various types of domains including the health domain, user profile and contextual information. Provides easy and open access to other (internal) software components for retrieving and updating information.

1 Introduction

In the Council of Coaches project a council of multiple embodied conversational coaches is being developed to provide tailored coaching on various domains (for example, physical activity and diet, but in this project also for the specific cases of Diabetes Type 2, Chronic Pain and Age-Related Impairments). Each coach will have their own specialization or coaching domain and the user will interact with several coaches at once.

The aim of this deliverable is to deliver an initial design for the coaching strategies and the shared knowledge base. To provide an impression of the inclusion of these elements in the final coaching system we will now first shortly describe the components to which they are connected.

When users of the Council of Coaches system join for a session with their personalised council, they will see a number of embodied conversational coaches. These coaches and their behaviours are portrayed using an Embodied Conversational Agent Platform (for which the initial technical design is further described in Deliverable 6.1). A Dialogue and Argumentation Framework (for which the initial technical design is described in Deliverable 5.1) generate the coaches' side of the dialogues and they sense the user through the Holistic Behaviour Analysis Framework (for which the initial technical design can be found in Deliverable 4.1).

To provide coaching that is tailored for every user specifically, the embodied conversational coaches will need a representation of the world they have to act in and their user. This representation will take the form of a knowledge base. What also has to be represented in this knowledge base are the coaches themselves. Just as human coaches can have personalities, preferences, and coaching strategies that they apply, embodied conversational coaches also need to know who they are and what they can do.

In this deliverable we will first describe the initial design process for the coaching strategies that the coaches will be able to apply, which will make up Section 3. We will then continue with the initial design of the knowledge base, which can be observed in Section 4.

2 Objectives

M6 of the Council of Coaches project (February 2018), marks the first crucial milestone in the project's lifespan. In this phase of the project, the initial designs of the four main technical components are delivered, and initial user- and stakeholder analysis has been performed. The results of this phase of the project are documented in the following series of five deliverables:

- D2.2: Report on user and stakeholder needs and expectations [**Stakeholder Analysis**]
- D3.1: Initial coaching strategies and knowledge base (*this deliverable*) [**Shared Knowledge Base**]
- D4.1: State-of-the-art, requirement analysis and initial specification of the Holistic Behaviour Analysis Framework [**Behaviour Analysis Framework**]
- D5.1: Dialogue and Argumentation Framework Design [**Dialogue Framework**]
- D6.1: Requirements and Concepts for Interaction Mobile and Web [**HCI Design**]

The overall strategy for the user-centred design and innovation process in the project is an iterative approach with rapid development and evaluation of three main prototypes and a final technical demonstrator. We strongly believe that the most valuable user input can be obtained from the evaluation of *working prototypes*. Therefore, the first prototype deliverable is scheduled for an early release in the project on M9 (May, 2018), allowing us to start the process of collecting concrete feedback from our users.

In order to achieve the delivery of a first prototype in M9, and due to the innovative nature of the project, multiple design and requirements elicitation trajectories are initiated simultaneously. Broadly speaking, the project initiates a "technology push" and "market pull" strategy simultaneously, as depicted in Figure 1.

This deliverable, depicted as "Shared Knowledge Base" in the figure contributes to both the market pull and technology push factors of the design and requirements phase, in line with the deliverable's two main objectives.

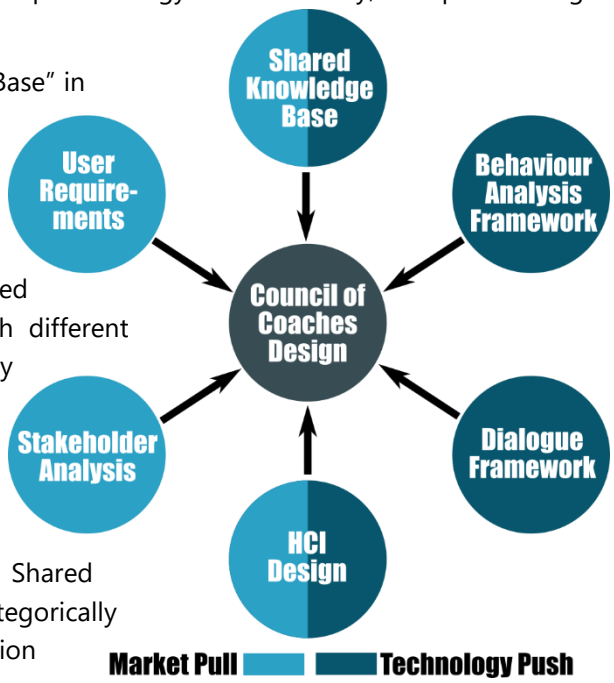

Figure 1: Global design and requirements elicitation process in the Council of Coaches project focusing on a simultaneous market pull and technology push strategy.

Objective 1: To provide a literature and expert based review on coaching strategies, identifying which different strategies exist, and what the user or personality factors are that influence their successful application (market pull). Additionally, we also look at the influence of the context on their application and how this might be leveraged.

Objective 2: To create an initial design of the Shared Knowledge Base component, being able to categorically store and provide access to the required information as identified in the coaching strategy review, and building on top of the state of the art in user and information modelling (technology push).

The coaching strategies are defined in Section 3, while the design of the Shared Knowledge Base is described in Section 4.

3 Coaching Strategies

As described in the previous chapter, the first objective of this deliverable is to provide a review of coaching strategies, which can be used as a source of information in designing the specific coaching actions that the coaches will apply (which will be the subject of Deliverable 3.2), and which can also be used in the determination of which user and personality factors influence the successful application of these coaching strategies.

In this chapter, we will start with providing information on theories of behaviour change (Section 3.1). Following these theories, we will provide an insight in existing coaching methods and how these relate to the theories (Section 3.2). We will then continue with an overview of specific behaviour change techniques that are applied when coaching (Section 3.3). While providing these overviews and insights we will identify elements that can be of interest to be included or represented in the shared knowledge base (that is, for example, user or personality factors, which might be used to fit strategies). We will mark these factors as represented in Figure 2. A summary and overview of all identified elements will be provided in Section 3.4.

Elements:

- User features
  - For example, age, gender
- User state features:
  - For example, motivation level
- Context features
  - For example, barriers, social support

Figure 2: An example of identified elements (with example text).

After providing an insight into the mechanisms that underlie behaviour change and the methods and techniques that a coach can apply to aid a user in achieving or keeping healthy behaviour, we will discuss some factors that are external, but can have a large influence on the effectiveness of coaching a user. These context and framing influences will be discussed in Section 3.5, since a coach could, for example, apply a very effective technique (for example, to send a reminder that it is time to get up and take a short walk outside), but if the context is not correct (for example, the user is at work and there is a blizzard going on) or the method of delivery is not optimal, then the intentions of the coach might be good, but the effect of the coaching action will not be as desired.

A diagram showing the steps described above can be found in Figure 3.

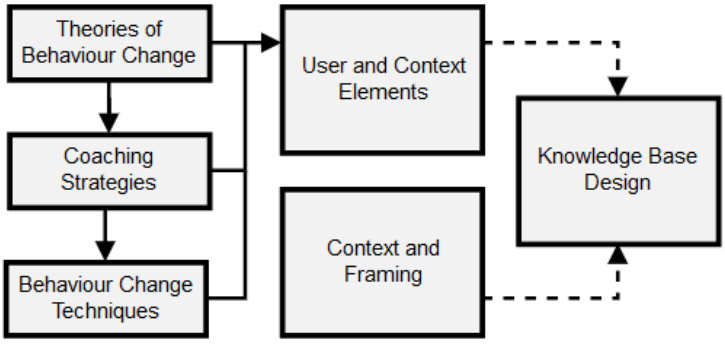

Figure 3: A diagram showing the steps in the process of designing and building the knowledge base that will be discussed in this section.

3.1 Theories of Behaviour Change

In the following subsections, an overview of behavioural change theories will be given by providing short summaries of these theories. These theories can be divided into groups in a number of ways. For example, continuous versus phase (or stage) models, behaviourist and cognitive models, or complete (behaviour in general) models versus models that model a small part of behaviour (for example, motivation or the effect of fear). In our summary we have chosen to order them as continuous versus phase models, and within that ordering chronologically. We will start with Operant Conditioning (3.1.1), followed by continuous models (3.1.2-3.1.10). Then we will discuss phase models (3.1.11-3.1.12) and finally the Health Action Process Approach, which is both a continuous and a phase model. A quick reference list for the behaviour change theories, their subsections and their references can be found in Table 1.

Section	Theory	Reference
3.1.1	Operant Conditioning	(Thorndike, 1927) (McLeod, 2007) (Miltenberger, 2011)
3.1.2	Health Belief Model	(Janz & Becker, 1984)
3.1.3	Perceptual Control Theory	(Carver & Scheier, 1982) (Carey & Mullan, 2008) (Powers W. T., 2009)
3.1.4	Social Cognitive Theory of Self-Regulation	(Bandura, 1991)
3.1.5	Information-Motivation-Behavioral Skills Model	(Fisher & Fisher, 1992)
3.1.6	Self-determination Theory	(Ryan & Deci, 2000)
3.1.7	Goal-setting Theory	(Locke & Latham, 2002)
3.1.8	Protection Motivation Theory	(Rogers, 1983) (Norman, Boer, & Seydel, 2005)
3.1.9	Fogg Behavior Model	(Fogg, 2009)
3.1.10	The Reasoned Action Approach	(Ajzen, 1991) (Fishbein & Ajzen, 2011) (Colman, 2015, p. 764)
3.1.11	The Rubicon Model of Action Phases	(Heckhausen & Gollwitzer, 1987) (Achtziger & Gollwitzer, 2007)
3.1.12	Transtheoretical Model of Health Behavior Change (Stages of Change)	(Prochaska & Velicer, 1997)
3.1.13	Health Action Process Approach	(Schwarzer, Lippke, & Luszczynska, 2011)

Table 1: An overview of the behavioural change theories summarized in this chapter listed with their corresponding subsections.

3.1.1 Operant Conditioning

Thorndike (Thorndike, 1927) formulated his Law of Effect as follows: "*Responses that produce a satisfying effect in a particular situation become more likely to occur again in that situation, and responses that produce a discomforting effect become less likely to occur again in that situation*."

In Operant Conditioning the consequences of behaviour are manipulated to change the subjects behaviour (Miltenberger, 2011, p. 141). In the process of conditioning, behaviourists treat the mind as a

black box and solely focus on providing motivation for behaviour change through outside factors. Skinner wrote down five consequences of behaviour for operant conditioning (McLeod, 2007) (also see Figure 4):

- Positive reinforcement. A positive stimulus is introduced. (e.g. a food reward).
- Negative reinforcement. A negative stimulus is removed. (e.g. stopping pressure)
- Positive punishment. A negative stimulus is introduced (e.g. applying pressure).
- Negative punishment. A positive stimulus is removed (e.g. removing food).
- Extinction. The reinforcements/punishments are stopped. The conditioned behaviour will continue at first, then it will become less and ultimately it will stop.

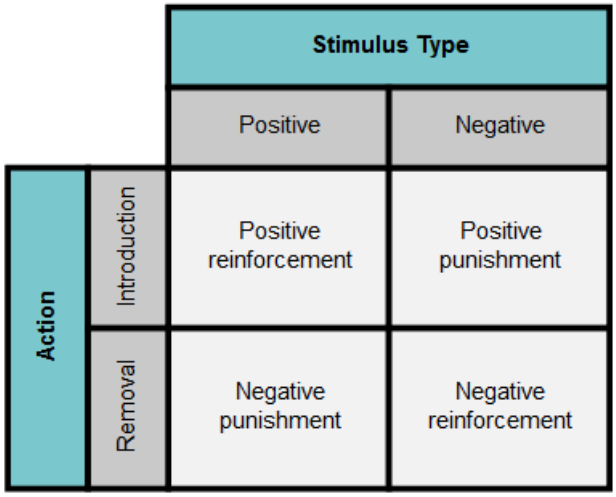

Figure 4: Four of the basic consequences related to changing the presence of a stimulus in Operant Conditioning.

The effectiveness of these consequences in changing the behaviour can be altered by several factors (Miltenberger, 2011, pp. 72-75):

- Satiation/deprivation (e.g. if a subject is not hungry, a food stimulus has less effect).
- Immediacy (an immediate consequence is more effective).
- Contingency (consistency in applying the stimulus makes it more effective).
- Size (a larger stimulus has more effect).

Elements:

- User state features:
  - Satiation/deprivation (and possible corresponding stimuli types)
  - Motivation level
  - Susceptibility for stimulus (e.g. % of behaviour occurring on stimulus)
- Context features:
  - Stimulus timing (when introduced)
  - Stimulus duration (presentation time)
  - Stimulus size
  - Stimulus effect (positive/negative)

3.1.2 The Health Belief Model

The Health Belief Model (Janz & Becker, 1984) is a model, developed in the early 1950s, that is used to explain and predict why individuals did or did not perform health related actions (for example, follow health care advice). The model has two main variables:

1) The desire (of an individual) to avoid illness (or to get well if ill).
2) The belief in the effect of a specific health action.

The model (see Figure 5) illustrates that perceived susceptibility to an illness and severity of that illness provide a need to act and perceived benefits and barriers influence which action will be taken, which will then be enacted when cues to action are present. These cues to action can be internal (for example, symptoms) or external (for example, reminders by a health care professional). The entire process can be influenced by factors that influence the individual's perception (for example, age, social class, peer pressure, knowledge about a disease, etcetera).

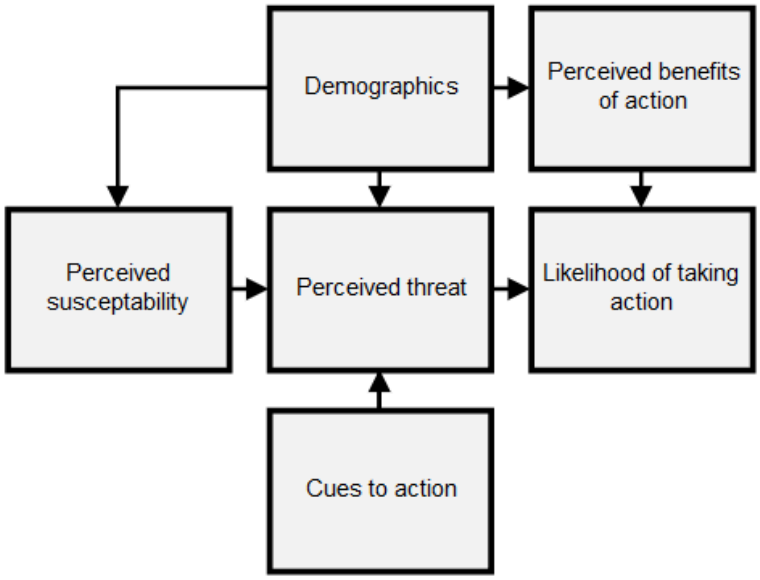

Figure 5: The Health Belief Model (scheme based on (Janz & Becker, 1984, p. 4)).

Elements:

- User features:
  - Demographic information
- User state features:
  - Perceived susceptibility
  - Perceived threat
  - Perceived benefits
  - Likelihood of taking action
- Context features:
  - Cues to action

3.1.3 Perceptual Control Theory

Perceptual Control Theory (Carver & Scheier, 1982) (Carey & Mullan, 2008) (Powers W. T., 2009) is a theory that focusses on self-regulation (or control). The basis of this theory is the control loop (see Figure

6): There is an input from the environment (perceived information), which is compared to an internal reference, which results in an output (behaviour) that will affect the environment. Therefore, Perceptual Control Theory models that individuals do not directly control their behaviour, but that they act to adjust their perceptions to fit a specific desired condition.

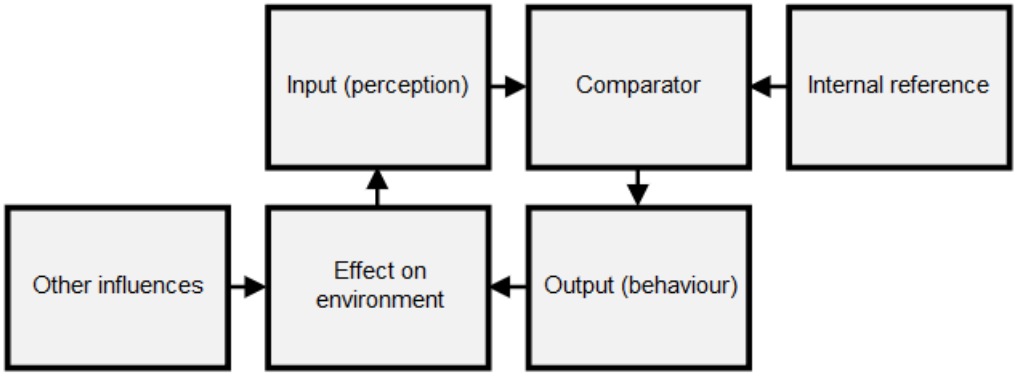

Figure 6: The feedback loop. Perceived information is compared to an internal reference, which results in behaviour, which affects the perceived information.

There are multiple levels at which comparison can take place, which are the levels of the perceptual hierarchy. Higher levels of perception are built upon lower ones. An example of a process on a higher level is having certain principles, and an example of a process on a lower level is sensing. The output of a higher level influences the levels below. A change to the references in lower levels might cause a disturbance in higher levels (that is, the input does not match reference, for example: hitting someone when wanting to be a decent person). Therefore, for some changes to the lower levels to occur, reorganization is required. Reorganisation can, for example, exist of changing reference values or adjusting connections between levels.

Elements:

- User features:
  - Resulting behaviour
- User state features:
  - Internal reference
- Context features:
  - Perceivable input

3.1.4 Social Cognitive Theory of Self-Regulation

Note: As can be observed, Social Cognitive Theory builds on Perceptual Control Theory and has influenced Goal Setting Theory.

Social Cognitive Theory (Bandura, 1991) is Bandura's extension to Social Learning Theory (Bandura, 1971). Social Learning Theory stated that someone can learn the effectiveness of behaviour through directly experiencing its effects or by observing the behaviour of others and its effects. Learning can also happen through observing rewards or punishments that are given (vicarious reinforcement). It can occur even if the individual is unaware of the behaviour they are rewarded for (see Figure 7).

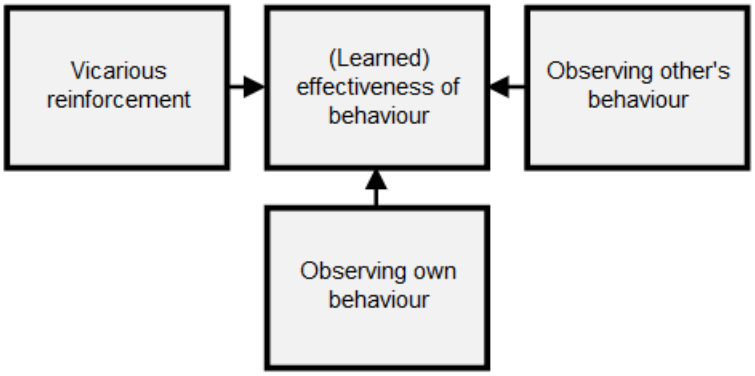

Figure 7: The influencing processes on learning the effectiveness of behaviour in Social Learning Theory.

Reinforcement is important in learning, but learning also involves the cognitive process of evaluating behaviour. The learner's cognition, behaviour and the environment all influence each other (reciprocal determinism; see Figure 8).

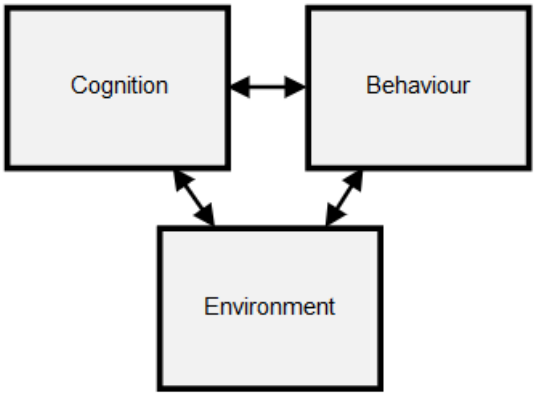

Figure 8: Reciprocal determinism in Social Learning Theory.

Social Cognitive Theory (SCT) (Bandura, 1991) states that human behaviour is motivated and regulated by the ongoing exercise of self-regulation. Self-regulation in SCT occurs through the following three sub processes:

- Self-monitoring. Observing (aspects of) your own behaviour.
- Self-judgement. Judging your own behaviour by comparing it to your standards/goals.
- Self-reaction. Responding to your own behaviour, either through changes in beliefs or actions.

In SCT future goals are not influencing behaviour directly, but there is anticipatory control which directs behaviour through current motivators and regulators (which are based on the anticipated future events).

An important concept that is introduced in SCT is the concept of self-efficacy, which is the belief an individual has about their own capabilities to exercise control over their behaviour and the environment. It is dependent on the individual's actual capabilities and self-confidence, but also on factors from the environment (for example, (perceived) barriers).

Elements:

- User features:
  - Capabilities (objectively)
- User state features:
  - Self-efficacy (barriers, capabilities, confidence, etc.)
  - Self-regulation
  - Learned effective behaviours
  - Reflection on own behaviour
  - Motivations
- Context features:
  - Reflection on other people's behaviour/results

3.1.5 Information-Motivation-Behavioural Skills Model

The Information-Motivation-Behavioral Skills Model (Fisher & Fisher, 1992), was formulated as a model for AIDS-risk behaviour reduction. It names three factors that influence the adoption of risk-reducing behaviour. These factors are available information/knowledge about the topic, motivation to change behaviour, and the availability of behavioural skills for performing the specific acts that are required (see Figure 9). Information and motivation influence each other, since knowing what healthy behaviour is can increase motivation to change and being motivated can power the search for more information about the subject. Both influence the availability of behavioural skills, since these can be gained by obtaining more knowledge and putting in effort. Information, motivation and behavioural skills finally will result in the adoption of the preferred behaviour since knowing about the healthy behaviour, and being motivated and capable to execute it increases the chance of performing the behaviour.

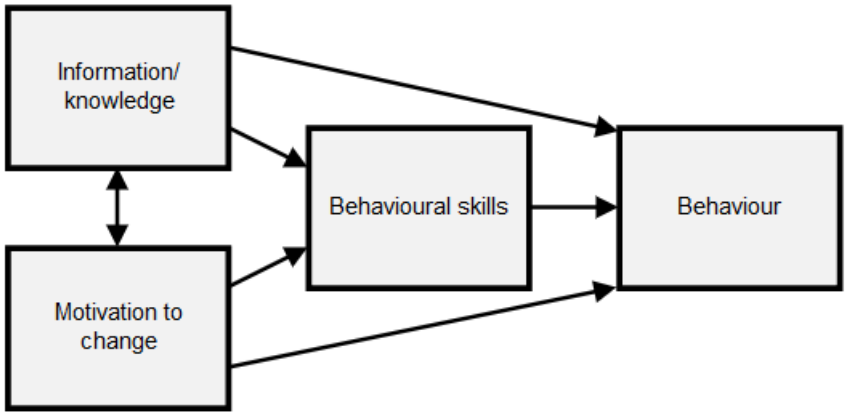

Figure 9: The Information-Motivation-Behavioral Skills Model (scheme based on (Fisher & Fisher, 1992, p. 465)).

Elements:

- User features:
  - Skills present
  - Behaviour occurring
- User state features:
  - Knowledge about skills and behaviour
  - Motivation for obtaining skills, behaviour, knowledge, and to change

3.1.6 Self-determination Theory

Self-determination Theory (SDT) (Ryan & Deci, 2000) focusses on the motivation individuals have for personality development and behavioural self-regulation. It states that there are three innate psychological needs whose presence influences these processes, namely: competence (wanting to control the results for something and become accomplished at it), relatedness (wanting to interact with, be connected to, and care for others), and autonomy (having control over your own life) (see Figure 10). Three types of motivation are distinguished: intrinsic (on own initiative, without external influence), extrinsic (with external influence), and a-motivation (no motivation).

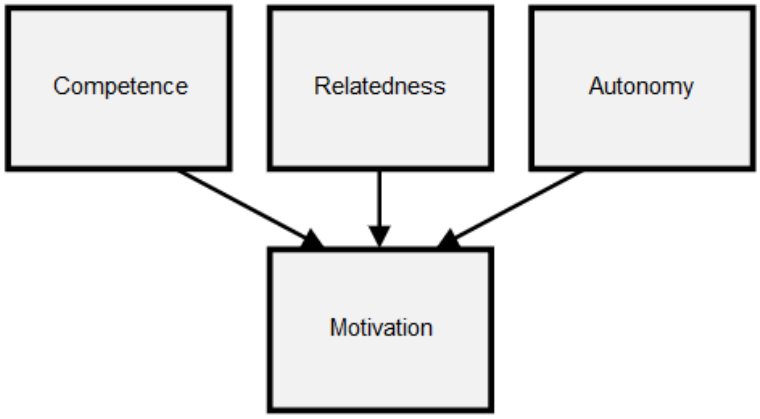

Figure 10: Self-Determination Theory.

Elements:

- User state features:
  - Competence
  - Relatedness
  - Autonomy
  - Motivation (intrinsic/extrinsic)

3.1.7 Goal-setting Theory

In Goal-setting Theory (Locke & Latham, 2002) the relationship between conscious goals or intentions and task performance is described (see Figure 11). Locke and Latham describe the influences on the transition from goals (defined by their core factors) to performance. These influences are divided into two groups, namely:

- Moderators. These influence the strength of the relationship between the goals and task performance.
- Mechanisms. These influence the effect that setting a goal has on task performance.

The individual's satisfaction with the performance on achieving their goal influences the effect the moderators have. There are two core factors for goals that have an influence on performance:

- Difficulty. The highest level of effort occurs when the goal difficulty is medium, a very easy or very difficult goal causes effort to be lower.
- Specificity. Setting specific goals is more effective than simply telling someone to 'do their best', since it provides the individual with a better view of when the goal is reached.

Setting goals affects performance through four mechanisms:

- Choice/Direction. Goals direct attention and effort toward goal-relevant activities – both cognitive and in behaviour.
- Effort. Goals have an energizing function. High goals lead to greater effort than low goals.
- Persistence. Participants will work harder or longer on a more difficult task.
- Strategies. Goals affect action indirectly by leading to arousal, discovery and/or use of task-relevant knowledge and strategies.

There are three moderators on goal effect:

- Commitment. A high commitment (for example, through increased importance) will lead to more effort in reaching difficult goals. Another factor that can add to goal commitment is self-efficacy, since having a higher self-efficacy leads to higher commitment. Achieving a goal can then increase self-efficacy, which in turn leads to setting higher goals (high-performance cycle).
- Feedback. If the participant knows how well they are proceeding towards a goal they will be able to increase their effort if they are below target.
- Task complexity. If a task is more difficult, people will apply more and more complex strategies to achieve the goal. Individuals with a higher self-efficacy set more difficult goals.

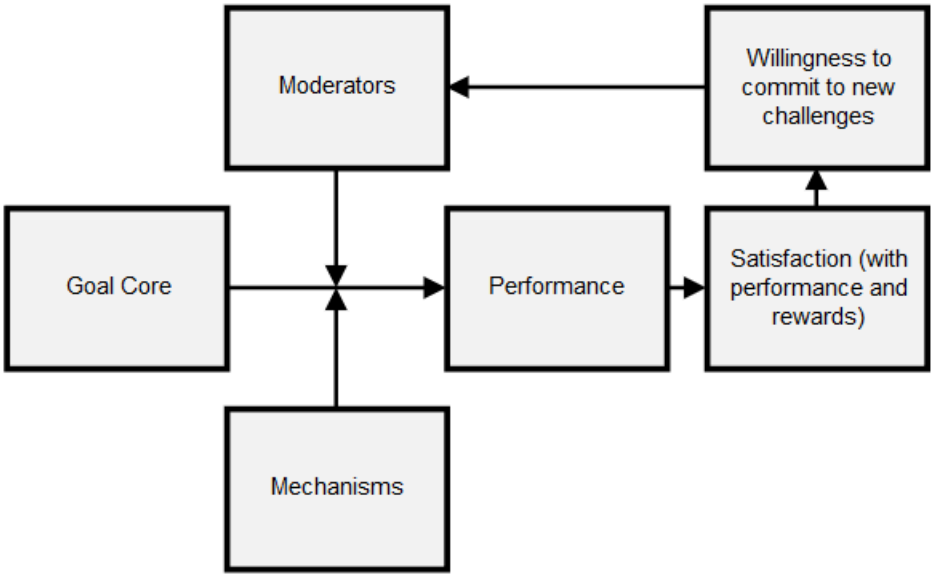

Figure 11: Goal-setting Theory (schema based on (Locke & Latham, 2002, p. 714)).

Elements:

- User state features:
  - Susceptibility for goal mechanisms
  - User commitment
  - Feedback received/effect
  - Task complexity for user
- Context features:
  - Goal persistence
  - Goal choice/direction
  - Goal strategies (available)
  - Goal effort

3.1.8 Protection Motivation Theory

Protection Motivation Theory (Rogers, 1983) (Norman, Boer, & Seydel, 2005) was developed by Rogers as a framework for understanding the impact of fear appeals. It was later extended to include the impact of persuasive communications in general.

The model states that there are two processes that can result from fear appeals (see Figure 12). Which process is followed is influenced by environmental and intrapersonal factors. These processes are:

- Threat appraisal. In this process an individual takes the severity of a threat and their vulnerability to it into account. In this case, fear might trigger self-protective behaviour. Intrinsic (for example, liking to smoke) and extrinsic (for example, social approval) motivation factors can also influence the execution of the self-protective behaviour.
- Coping appraisal. In this process the individual focusses on how to cope with the threat. In this case, response efficacy (the recommended behaviour will work) and self-efficacy (believing in being capable of performing the behaviour) can trigger behaviour change, but response costs (or barriers) also influence the execution of the self-protective behaviour.

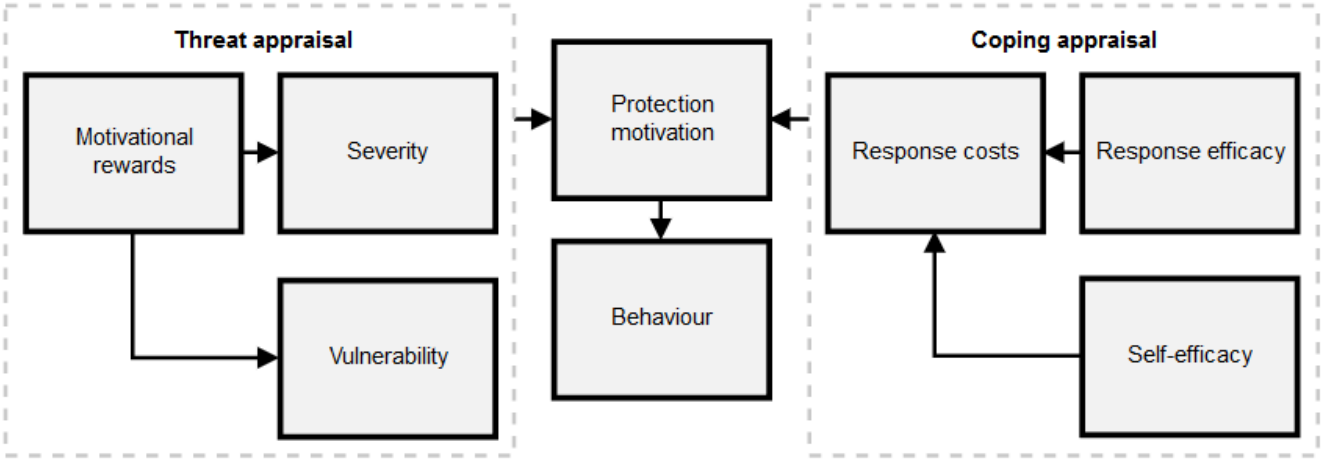

Figure 12: Protection Motivation Theory (scheme based on (Norman, Boer, & Seydel, 2005, p. 84)).

Elements:

- User features:
  - Vulnerability for threat
- User state features:
  - Perceived severity of threat
  - Perceived vulnerability for threat
  - Motivation (intrinsic / extrinsic)
  - Self-efficacy
  - Response efficacy
  - Response costs
- Context features:
  - Severity of threat

3.1.9 Fogg Behavior Model

The Fogg Behavior Model (Fogg, 2009) defines behaviour as a product of three factors: motivation, ability and triggers (see Figure 13). It describes that in order for an individual to perform a behaviour they must be sufficiently motivated and able, and then activated by a trigger with the correct timing.

Fogg first defines three core motivators that can be used to increase an individual's motivation level:

- Pleasure/pain
- Hope/fear
- Social acceptance/rejection.

He goes on to define the increase of ability to perform behaviour as an increase of simplicity of the behaviour. He names six simplicity influencing factors, which are: time, money, physical effort, brain cycles (having to think), social deviance (going against societal norms), and non-routine.

Finally, Fogg defines three types of triggers, which can be used when different motivation-activity combinations are present:

- Sparks (low motivation). A trigger that includes a motivational element (either positive or negative).
- Facilitator (high motivation, low ability). A trigger for the behaviour that also makes the behaviour easier to perform.
- Signal (high motivation, high ability). A trigger that simply serves as a reminder that the behaviour has to be performed.

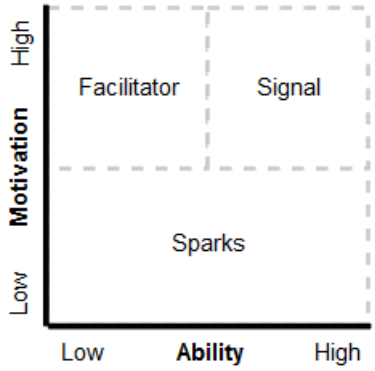

Figure 13: The Fogg Behavior Model. Indicated are the types of triggers and in which motivation-ability situations they are effective. The execution of target behaviour becomes more likely with high motivation and high ability (scheme based on (Fogg, 2009, p. 5)).

Elements:

- User state features:
  - Motivation level
  - Ability of performing behaviour
- Context features:
  - Pleasure as motivation
  - Fear as motivation
  - Social acceptance as motivation

3.1.10 The Reasoned Action Approach

The Reasoned Action Approach (Fishbein & Ajzen, 2011) is the latest version of the theory by Fishbein and Azjen. It is an extension of the Theory of Planned Behaviour (Ajzen, 1991), which added to the Theory of Reasoned Action (Colman, 2015, p. 764) (see Figure 14).

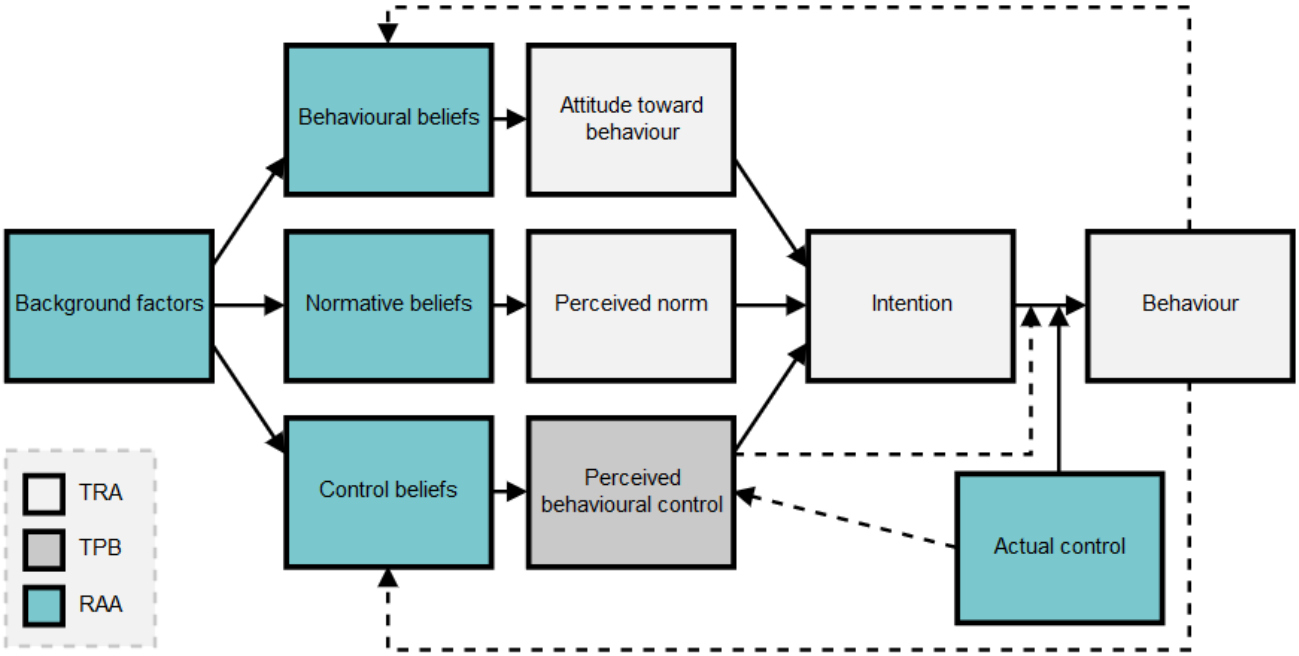

Figure 14: The Reasoned Action Approach. Indicated in light grey are the elements from the Theory of Reasoned Action, to which the dark grey element was added in the Theory of Planned Behaviour. These grey elements combined with the blue elements form the Reasoned Action Approach (scheme based on (Colman, 2015), (Ajzen, 1991) (Fishbein & Ajzen, 2011).)

The Theory of Reasoned Action stated that the intention of an individual to engage in behaviour is a result of the attitudes to that behaviour and subjective norms (perceived norm). For this intention to result in actual behaviour there are three conditions to be met: the intention must be as specific as the behaviour, the intention must not change before performing the behaviour, and the individual always has the control in performing the behaviour.

In the Theory of Planned Behaviour, Azjen added another predictor, namely: perceived behavioural control (Ajzen, 1991). As its name suggests, this factor represents the confidence an individual has in their ability to perform the behaviour. Azjen also states that of various views on control the view on perceived behavioural control is most compatible with Bandura's concept of self-efficacy.

In the Reasoned Action Approach Fishbein and Azjen make two additions to their model. The first is the addition of beliefs as an influence to the three intention influencers (attitude toward behaviour, perceived norm, and perceived behavioural control). These beliefs are influenced by the individual's background factors (for example, age, social class, and information available). The second addition is that of an actual control element (for example, skills, and opportunity), which indirectly influences perceived behavioural control and also directly influences the process of intentions becoming actual behaviour.

Elements:

- User features:
  - Background
  - Behavioural skills
  - Actual behavioural control
- User state features:
  - Behavioural beliefs
  - Normative beliefs
  - Control beliefs
  - Attitude towards behaviour
  - Perceived norm
  - Perceived behavioural control (±self-efficacy)
  - Intention
- Context features:
  - Barriers
  - Opportunity

3.1.11 The Rubicon Model of Action Phases

The Rubicon Model of Action Phases (Heckhausen & Gollwitzer, 1987) (Achtziger & Gollwitzer, 2007) models the selection and realization of goals. The use of Rubicon in the name is a reference to the crossing of the Rubicon by Julius Caesar, who made a decision to achieve a goal and thus committed himself to that goal (which in this model is the transition between the predecisional and the postdecisional phase). Successful goal pursuit is described as a combination of four phases (see Figure 15):

- Predecisional phase. In this phase a goal is chosen based on capabilities, desires, feasibility, etcetera. The individual has a deliberative mindset (based on motivation and focussed on setting goals).
- Postdecisional phase. In this phase the implementation of a goal is planned (when, where, how). The individual has an implemental mindset (based on volition and focussed on taking action).
- Actional phase. In this phase actions towards the goal are performed.
- Postactional phase. In this phase the achievement is assessed by comparing it to what needs to be achieved.

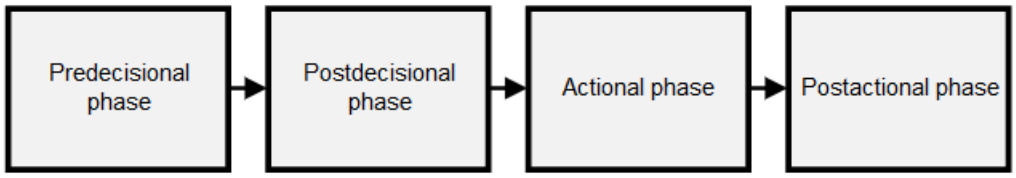

Figure 15: Rubicon Model of Action Phases.

Elements:

- User features:
  - Capabilities
- User state features:
  - Desires
  - Perceived goal feasibility
  - Mindset (deliberative/implemental)
  - Assessment of achievement
  - Desired new goals
- Context features:
  - Actions (and their state of execution)
  - Goal when, where, how possibilities
  - Possible new goals

3.1.12 Transtheoretical Model of Health Behavior Change (Stages of Change)

The Transtheoretical Model (Prochaska & Velicer, 1997) defines six stages of change that people go through before reaching behavioural change. These stages are the following (see Figure 16):

- Precontemplation. There is no intention to change behaviour.
- Contemplation. The individual thinks about changing their behaviour.
- Preparation. There is intention to change and some actions have been taken to prepare for the actual change.
- Action. Specific modifications have been made to the current behaviour.
- Maintenance. The individual has to actively prevent relapse.
- Termination. The individual has zero temptation to relapse and 100% self-efficacy. They will not return to the old behaviour.

During the process of going through these stages, people can also relapse, which means that they return to one of the previous stages.

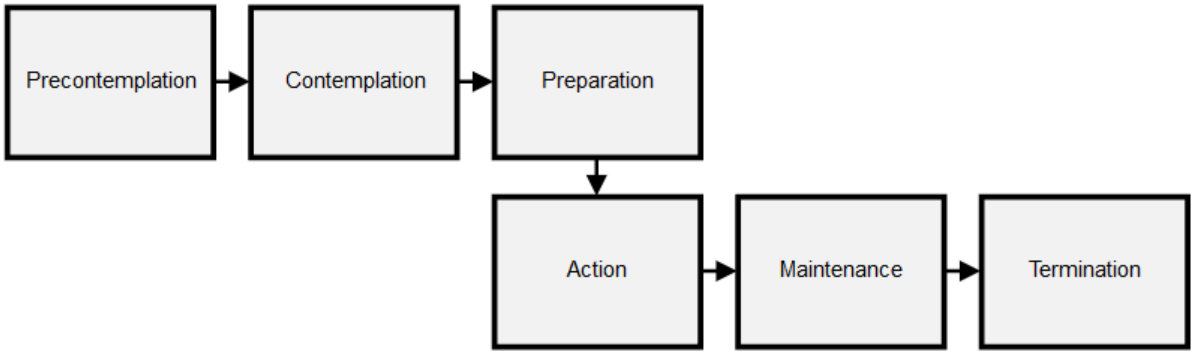

Figure 16: The Stages in the Transtheoretical Model of Health Behavior Change.

The model also names ten processes of change which are the means for individuals to progress through the stages. These are: consciousness raising (gaining information and awareness), dramatic relief (being aware of the emotions that are present or arise), self-re-evaluation (effects of behaviour on self), environmental re-evaluation (effects of behaviour on environment), self-liberation (the belief that one can change and (re)commitment to that belief), social-liberation (the availability of social opportunities), counterconditioning (learning healthier behaviours to substitute problem behaviours), stimulus control

(removing cues for unhealthy behaviour and adding them for healthier behaviours), contingency management (providing consequences for taking steps in a particular direction, that is, reinforcement/punishment), and helping relationships (for example, support or buddy systems).

Finally, there are three important factors that influence going through the stages as well. These are:

- Decisional balance. The individual's relative weighting of the pros and cons of changing.
- Self-efficacy. The situation specific confidence people have in their own capabilities and coping skills when it comes to achieving behaviour change. This concept was integrated from Social Cognitive Theory.
- Temptation. The intensity of urges to engage in a specific habit when in a difficult situation (emotional distress, positive social situations, and craving).

Elements:

- User features:
  - Actions taken
- User state features:
  - Intention level
  - State of change
  - Preparative steps taken
  - Chance of relapse
  - Self-efficacy
  - Information obtained
  - Awareness level (e.g. effect of behaviour on self)
  - Emotional state
  - Self-liberation beliefs
  - Counterconditioning/stimulus susceptibility
  - Decisional balance
  - Temptation susceptibility (e.g. emotional distress, positive social situations, cravings etc.)
- Context features:
  - Effect of user behaviour on environment
  - Counterconditioning options
  - Stimulus presence
  - Contingency management (positive/negative)
  - Helping relationships

3.1.13 Health Action Process Approach

The Health Action Process Approach (HAPA) (Schwarzer, Lippke, & Luszczynska, 2011) is a self-regulation framework that can be applied in health promotion for people with chronic illnesses or disabilities (see Figure 17). It was developed in 1988 as an attempt to integrate the Rubicon Model of Action Phases and Social-Cognitive Theory. As a result, HAPA has two layers (or types of processing) that can be chosen depending on the research question, that is, a continuum layer and a phase (or stage) layer. In the HAPA, goal setting (motivation) and goal pursuit (volition) are seen as two distinctive phases. There are five major principles:

- Motivation and volition. There is a switch of mindsets when people go from deliberation to action. Therefore, these are two separate phases.
- Two volitional phases. There are people for whom actions still have to be formed from intentions (preintention). There are also people who have made this step (intention, and action).
- Postintentional planning. Planning is a key strategy to make the transition from intention to action.
- Two kinds of mental simulation. Two types of planning can be distinguished: action planning and coping planning. Action planning includes the where, when and how of an action. Coping planning includes the anticipation of barriers and designing alternative actions.
- Phase-specific self-efficacy. There are three types of self-efficacy that are distinguished in this case: preactional (or task), coping (or maintenance) and recovery.

The HAPA also lists examples taken from the physical activity domain for measuring nine theory-implied constructs, namely: behaviour, intention, planning, action control, self-efficacy, risk perception, outcome expectancies, social support, and stage algorithms (that is, methods of allocating participants to stages, for example, by means of a questionnaire).

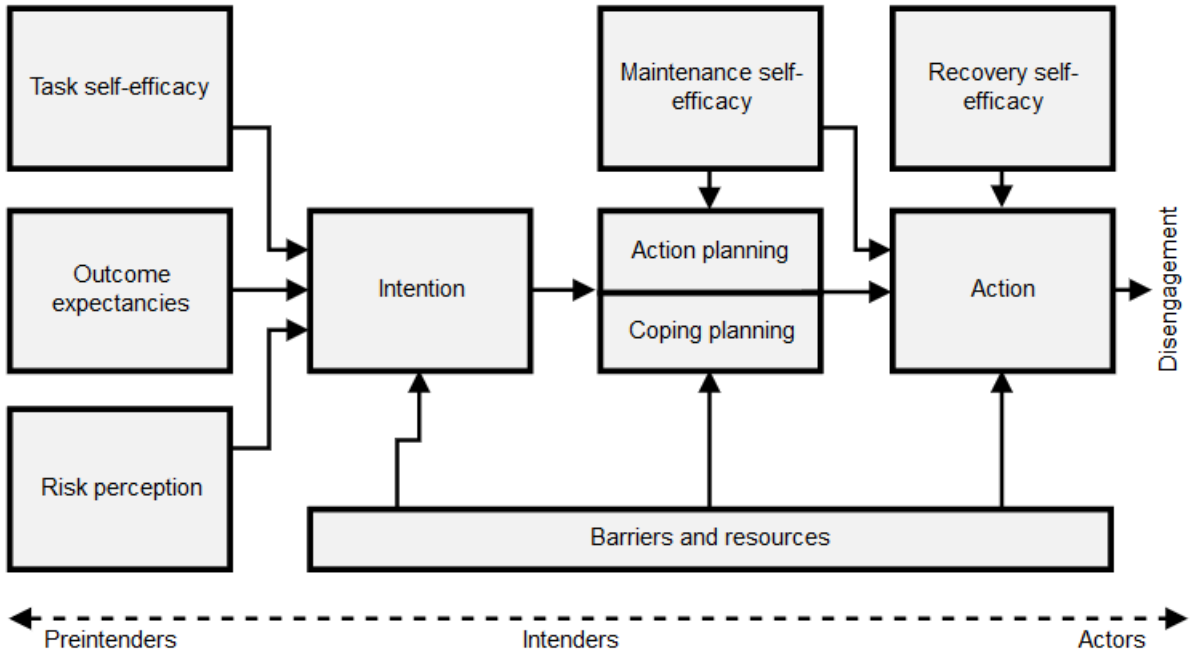

Figure 17: The Health Action Process Approach (scheme based on (Schwarzer, Lippke, & Luszczynska, 2011, p. 2).

Elements:

- User state features:
  - Mindset (deliberation/action)
  - Intention stage (preintention/intention/action)
  - Planning of actions
  - Coping planning
  - Action planning
  - Self-efficacy (maintenance/coping, recovery, task/preactional)

3.2 Coaching Methods

The Coaching Manual (Starr, 2007) states that a conversation is a coaching conversation if the person being talked to agrees that:

- They and their circumstances are the subject
- Their thinking/actions/learning benefitted significantly
- They were unlikely to have had these benefits anyway if the conversation had not happened.

But, as is often the case, there is not one single method for effective coaching. In the following subsections we will summarize various coaching methods and describe how they relate to the behaviour change theories listed above. A quick reference list for these coaching methods, their subsections and references can be found in Table 2.

Section	Coaching method	Reference
3.2.1	Cognitive Behavior Therapy	(Beck, 2011)
3.2.2	Motivational Interviewing	(Miller & Rollnick, Motivational Interviewing: Helping People Change, 2012) (Markland, Ryan, Tobin, & Rollnick, 2005)
3.2.3	Motivational Enhancement Therapy	(Miller, 1995)
3.2.4	Twelve-step Facilitation Therapy	(Kingree, 2013) (Nowinski, Baker, & Carroll, 1992)
3.2.5	The Method of Levels	(Carey & Mullan, 2008)
3.2.6	Planning interventions	(Hagger & Luszczynska, 2014)
3.2.7	Diabetes specific coaching	(Powers, et al., 2015) (Chrvala, Sherr, & Lipman, 2016) (Sherifali, 2017)
3.2.8	Chronic pain specific coaching	(McCracken & Vowles, 2014)

Table 2: An overview of the coaching methods summarized in this chapter listed with their corresponding subsections.

3.2.1 Cognitive Behavior Therapy

Cognitive Behavior Therapy (Beck, 2011) has the underlying theory that coaching to solve all of a person's problems will be more effective than simply trying to quit the resulting problem behaviour (for example, alcohol abuse), since emotions, thoughts and behaviours all influence each other. The therapy can be related to, for example, Social Cognitive Theory, since cognition has a large part in changing behaviour, but there are influences of the environment as well.

3.2.2 Motivational Interviewing

Motivational Interviewing (Miller & Rollnick, 2012) (Markland, Ryan, Tobin, & Rollnick, 2005) is a coaching method aimed at enhancing intrinsic motivation to change and supporting self-efficacy. Clients will often have conflicting motivations (for example, wanting to change behaviour to be healthier, but also liking the reward of the unhealthy behaviour). During motivational interviewing clients can express this dilemma and the intention is to let them decide to change their behaviour. Motivational Interviewing is directive in that it wants to help the client change, but it will not impose goals or strategies (to prevent the client form taking the opposite stance). In a systematic review by Wolever et al. on health and wellness coaching it is stated that Motivational Interviewing was applied in 42% of the reviewed cases (Wolever, et al., 2013).

When relating Motivational Interviewing to the behaviour change theories listed in the previous section there are several references that can be made. The process that the individual goes through, for example, can be seen as moving from the contemplation stage to the preparation stage (and maybe even the action stage) in the Transtheoretical Model. Another reference that can be made is that of the concept of motivation as described in Self-determination Theory, since the coach's ultimate goal is to elicit intrinsic motivation in the client.

3.2.3 Motivational Enhancement Therapy

Motivational Enhancement Therapy (Miller, 1995) is based on Motivational Interviewing, which means that it aims to enhance intrinsic motivation, but it also uses information provided by the client and information from available research to offer direct advice. As has been mentioned above, Motivational Interviewing can be related to the Transtheoretical Model and Self-determination Theory. Since this therapy also involves direct advice based on information presented, it also has elements that can be related to the Information-Motivation-Behavioural Skills Model.

3.2.4 Twelve-step Facilitation Therapy

Twelve-step Facilitation Therapy (Kingree, 2013) (Nowinski, Baker, & Carroll, 1992) is a therapy aimed at individuals with a substance dependency. There are two major treatment goals: acceptance and surrender. Then there are groups of objectives that reflect these major treatment goals, which are: cognitive, emotional, behavioural, social, and spiritual. During the treatment there are 12 sessions, of which 2 involve a patient's partner (if applicable), and a maximum of 2 individual emergency sessions can be added. During these sessions, the coach will help a patient evaluate, provides information and attempts to motivate in adopting the healthy behaviour. They will also help the patient set goals and provide coping techniques. In terms of theories, the Twelve-step Facilitation Therapy can be related to the Information-Motivation-Behavioral Skills Model.

3.2.5 The Method of Levels

The Method of Levels (Carey & Mullan, 2008) was developed based on Perceptual Control Theory. This psychotherapy aims to shift the attention of an individual to the highest level of their problems in order to resolve the conflict between levels through reorganisation. This is done by assisting the individual in focussing on their background thoughts.

3.2.6 Planning Interventions

Planning Interventions are a group of coaching methods that involve teaching the client how to formulate and use techniques for planning the execution of behaviour such as, for example, Implementation Intentions and Action Planning (Hagger & Luszczynska, 2014).

The Implementation Intentions method is about formulating responses to specific situations using an 'if-then' structure ('If I get offered chocolate, then I will say 'No'"). These situations are based on occurrences in the environment and not on internal states. Implementation Intentions can be related to the Rubicon Model of Action Phases as an underlying behaviour change theory, that is, a goal is chosen (predecisional phase), planned (postdecisional phase), and executed (actional phase).

Action Planning is a method that appears as a concept in, for example, the Health Action Process Approach (which, as described previously, attempted to integrate the Rubicon Model and Social-Cognitive Theory) and it is a method that is frequently used in interchange with Implementation Intentions. One of the differences that can be noted between the two is that Action Planning also emphasises the 'how' in planning an action. It can also include attempts to narrow the gap between plans and actions through, for example, coping plans.

3.2.7 Diabetes Specific Coaching

Diabetes self-management education and support methods (or diabetes self-management training) (DSME) are methods in diabetes care that aim to facilitate the development of knowledge, skills, and abilities that are required for successful self-management. (Chrvala, Sherr, & Lipman, 2016) performed a systematic review on the effect that these methods have on glycaemic control. Or to be more specific: the effect that the described DSME has on the A1C value (also known as HbA1c, glycated haemoglobin or glycosylated haemoglobin), which is an indication of the average blood sugar levels in the last two to three months (a higher A1C means poorer blood sugar control and thus a higher risk of complications from diabetes). As with other types of coaching there is a large variability in the specific contents of DSME approaches. The studies reviewed by Chrvala et al. (2016) focussed on type 2 diabetes. They did not perform a meta-analysis due to the large variability in DSME contents. They did conclude that all methods of DSME achieved greater reductions in A1C for their participant groups than were observed for their control groups.

In the paper describing their joint position statement, the American Diabetes Association, the American Association of Diabetes Educators, and the Academy of Nutrition and Dietetics state that all individuals with diabetes should receive DSME at diagnosis and as needed thereafter (Powers, et al., 2015). They provide a 'diabetes education algorithm' which is an evidence-based scheme that depicts when to refer individuals for DSME (Figure 3 in (Powers, et al., 2015)). They also provide a guideline for the content and action steps of DSME at four critical time points (their Figure 4).

Finally, (Sherifali, 2017) proposes a diabetes coaching model that identifies four factors:

- Personal case management and monitoring (emphasizing process of care issues and system navigation related to diabetes).
- Diabetes self-management education and support (highlighting the need for knowledge, skill acquisition, and problem solving related to day-to-day management).
- Behaviour modification, goal setting and reinforcement (using motivational interviewing and theories to facilitate goal setting, attainment and behaviour change).
- General psychosocial support (active listening and empathy to provide support).

3.2.8 Chronic Pain Specific Coaching

Chronic Pain coaching focusses on pain management, empowerment, dealing with fear and frustration, acceptance and learning to live in the present. Cognitive Behaviour Therapy (CBT) can be used for Chronic Pain, but its effectiveness has limits. A version of CBT that is effective for Chronic Pain is Acceptance and Commitment Therapy (ACT) (McCracken & Vowles, 2014). ACT involves acceptance and mindfulness methods, activation and behaviour change methods ('accept, choose and take action' (McCracken & Vowles, 2014)). Also important in ACT is a functional contextual framework that views thoughts and feelings in their context instead of simply 'good' or 'bad'. Acceptance has been found to be a strong indicator of treatment effectiveness for Chronic Pain.

3.3 Behaviour Change Techniques

There are many techniques a coach can apply during a coaching session. An often encountered problem in the literature on coaching was that in papers describing the application of a coaching methods there would be no description of the techniques that the applied coaching involved and how it would be applied. This makes comparing the different applications of coaching methods difficult. With the goal of introducing a standardized description method for behaviour change techniques, Abraham & Michie published 'A taxonomy of behaviour change techniques used in interventions' (Abraham & Michie, 2008), which included descriptions for 22 techniques (and 4 very popular sets of techniques). An example they provided was that using these standardized descriptions there would no longer be the issue of

reading 'we applied goal-setting' and not knowing whether this had also included self-monitoring and feedback or not.

In 2013 they published a new version of the Behavior Change Technique Taxonomy (v1) (BCTTv1) (Michie, et al., 2013) that lists 93 different behaviour change techniques grouped in 16 categories. For each technique it also includes a definition and examples. The categories are the following:

1. Goals and planning (for example, goal setting (behaviour), and behavioural contract)
2. Feedback and monitoring (for example, self-monitoring of behaviour, and biofeedback)
3. Social support (unspecified, practical, and emotional social support)
4. Shaping knowledge (for example, instruction on how to perform the behaviour, and re-attribution)
5. Natural consequences (for example, information about health consequences, and anticipated regret)
6. Comparison of behaviour (for example, social comparison)
7. Associations (for example, prompts/cues, and remove access to the reward)
8. Repetition and substitution (for example, behavioural practice/rehearsal, and graded tasks)
9. Comparison of outcomes (for example, credible source, and pros and cons)
10. Reward and threat (for example, material incentive (behaviour), and future punishment)
11. Regulation (for example, pharmacological support, and conserving mental resources)
12. Antecedents (for example, restructuring the physical environment, and distraction)
13. Identify (for example, framing/reframing, and valued self-identify)
14. Scheduled consequences (for example, behaviour cost, and situation-specific reward)
15. Self-belief (for example, focus on past success, and self-talk)
16. Covert learning (imaginary punishment, imaginary reward, vicarious consequences)

(It is also noted that an additional technique 'increase positive emotions' will be included in BCT Taxonomy v2.)

Many of these techniques can be related to the behaviour change theories described previously and they therefore share elements that we identified for these theories.

3.4 Summary of Elements

Below we will list the elements that we identified for the behaviour change theories. We have divided these elements into three groups:

- User features. Elements that contain information about the user which can be objectively observed as an external viewer.
- User state features. Elements that are internal or (part of) internal processes.
- Context features. Elements that are not directly influenced or related to the user, but that can have a strong impact on the user's behaviour and behaviour change.

To increase readability, we have made an initial grouping of elements within these three groups, but this is neither a definite nor complete grouping.

User features:

- Demographic / background information (1.2, 1.10)
- Behaviour demonstrated / actions taken (1.3, 1.5, 1.12)
- Capabilities / (behavioural) skills (1.4, 1.5, 1.10, 1.11)
- Vulnerability for threat or risk (1.8)
- Actual behavioural control (1.10)
- Behaviour occurring on stimulus ratio (or the other way around) (1.1)

User state features:

- Motivation
  - Level (1.1, 1.9)
  - Type (intrinsic/extrinsic) (1.6, 1.8)
  - For which behaviour/outcomes (1.4)
    - Obtaining skills (1.5)
    - Performing behaviour (1.5)
    - Obtaining knowledge (1.5)
    - To change (1.5)
  - Competence (1.6)
  - Relatedness (1.6)
  - Autonomy (1.6)
- Susceptibility for stimuli/triggers/external influences / counterconditioning (1.12)
  - Satiation/deprivation (1.1)
  - Likelihood of taking action (1.2)
  - Temptation increasing factors (emotional distress, positive social situations, cravings) (1.12)
  - Chance of relapse (1.12)
- Susceptibility for undesirable consequences (illness, etc.)
  - Perceived susceptibility (1.2)
  - Perceived threat (1.2)
  - Perceived severity of threat (1.8)
  - Perceived vulnerability for threat (1.8)
  - Likelihood of taking action (1.2)
- Perceived behavioural control / self-efficacy (1.4, 1.8, 1.10, 1.12)
  - Barriers (1.4)
  - Perceived barriers (1.4)
  - Capabilities (1.4)
  - Perceived capabilities (1.4)
  - Confidence (1.4)
  - Phase-specific self-efficacy (maintenance/coping, recovery, task/preactional) (1.13)
- Behaviour / action
  - Benefits
  - Perceived benefits (1.2)
  - Learned effectiveness (1.4)
  - Knowledge about behaviour (1.5)
  - Ability of performing behaviour (1.9)
  - Likelihood of taking action (1.2)
  - Reflection on own behaviour (1.4)
  - Response behaviour:
    - Response efficacy (1.8)
    - Response costs (1.8)
  - Behavioural beliefs (1.10)
  - Attitude towards behaviour (1.10)
- Skills
  - Knowledge about skills (1.5)
  - Information obtained (1.12)
- Mindset / beliefs

    - State of change (1.12)
    - Intention stage (preintention/intention/action) (1.13)
    - Mindset (deliberation, implemental/action) (1.11, 1.13)
    - Internal reference (1.3)
    - Normative beliefs (1.10)
    - Control beliefs (1.10)
    - Perceived norm (1.10)
    - Intention (1.11)
    - Desires (1.11)
    - Assessment of achievement (1.11)
    - Awareness level (e.g. effect of behaviour on self) (1.12)
    - Emotional state (1.12)
    - Self-liberation beliefs (1.12)
    - Intention level (1.12)
    - Decisional balance (1.12)
- Goals / goal-setting
    - Susceptibility for goal mechanisms (1.7)
    - User commitment (1.7)
    - Feedback received/effect (1.7)
    - Task complexity for user (1.7)
    - Perceived goal feasibility (1.11)
    - Desired new goals (1.11)
    - Coping planning (1.13)
    - Action planning (1.13)
    - Preparative steps taken (1.12)

Context features:

- Stimuli / triggers
    - Timing (when introduced) (1.1)
    - Duration (presentation time) (1.1)
    - Size (1.1)
    - Effect (positive/negative) (1.1)
    - Cues to action (1.2)
    - Perceivable input (1.3)
    - Counterconditioning options (1.12)
    - Stimulus presence (1.12)
- Goals
    - Persistence (1.7)
    - Choice/direction (1.7)
    - Strategies (available) (1.7)
    - Effort (1.7)
    - When, where, how, possibilities (1.11)
    - Possible new goals (1.11)
- Threats:
    - Severity (1.8)
- Motivation:
    - Pleasure (1.9)
    - Fear (1.9)
    - Social acceptance (1.9)

        - Contingency management (positive/negative) (*adding rewards to actions*) (1.12)
- Circumstances:
    - Barriers (1.10)
    - Opportunity (1.10)
    - Helping relationships (1.12)
- Behaviour / actions:
    - Actions (and their state of execution) (1.11)
    - Effect of user behaviour on environment (1.12)
- Reflection on other people's behaviour/results (1.4)

Diabetes Type 2 and Chronic Pain specific information should also be included.

3.5 Context and Framing

As has already been mentioned when discussing some of the theories, an important influence on the occurrence of the preferred behaviour can be external factors. Whether these factors consist of extrinsic motivations, triggers, barriers, or social influences (to name a few examples that are also listed in the previous Section under 'Context Features'), they are important to take into account when defining strategies and required knowledge for a coaching system.

A well-known model for designing systems that takes external factors into account is the Persuasive Systems Design (PSD) Model (Oinas-Kukkonen & Hajumaa, 2009) (Lehto & Oinas-Kukkonen, 2011) (see Figure 18). It describes a framework for designing and evaluating persuasive systems. This framework builds on theories such as, for example, Goal-setting Theory (discussed in Section 3.1.7) and the Theory of Reasoned Action (discussed in Section 3.1.10). The development of persuasive systems exists of three phases according to Oinas-Kukkonen & Hajumaa (2009): understanding key issues behind persuasive systems, analysing the persuasion context, and designing system qualities.

In the following subsections we will discuss the external factors that should be taken into account for the Council of Coaches. We will first discuss the context. Then we will describe possible manners of tailoring, and finally, we will discuss delivery style, politeness and dialogue structure. While doing so we will provide an example of how these external factors are included in the literature. This will be done by referring to specific papers on what we identify as important elements and to the PSD Model, which is more general.

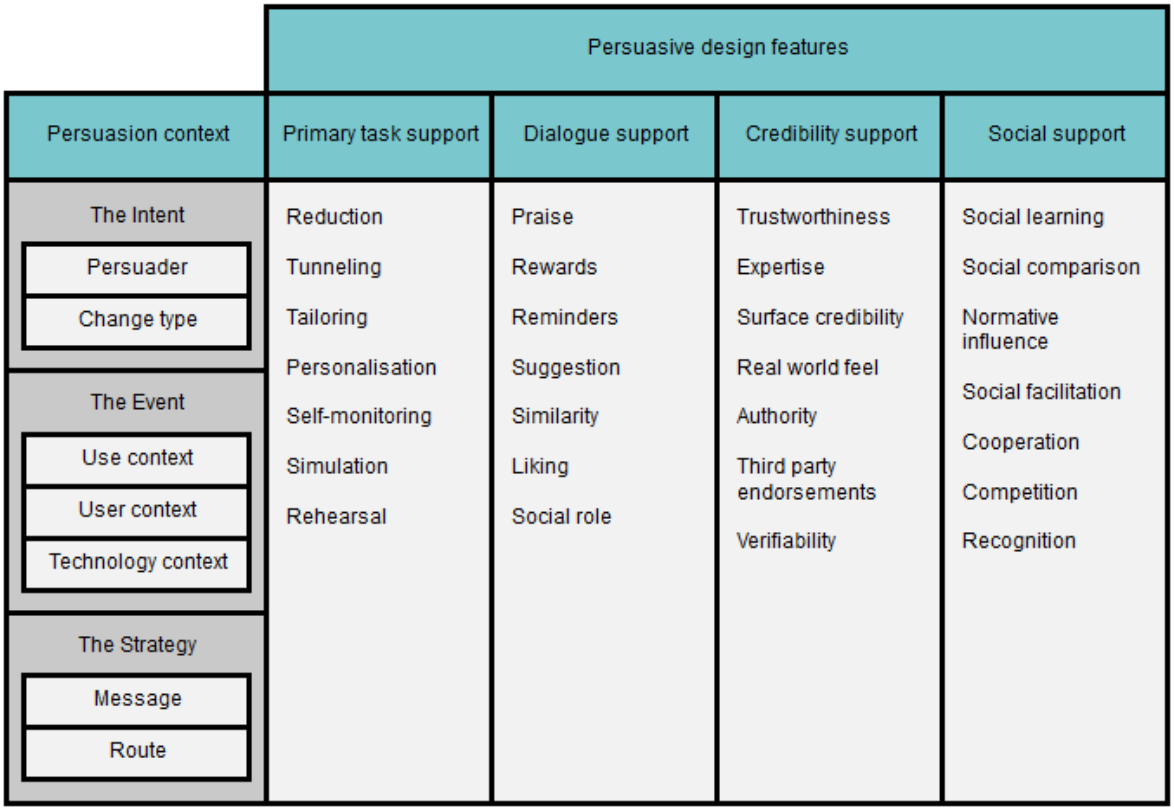

Figure 18: The Persuasive Systems Design Model as depicted and described in (Lehto & Oinas-Kukkonen, 2011), which was based on (Oinas-Kukkonen & Hajumaa, 2009, p. 487).

3.5.1 Context

When referring to context in this subsection and the following subsections, we mean the situation in which coaching is applied that involves the previously mentioned external factors, or the 'use context' as it is called in the PSD model. This involves aspects of the environment in which the user is situated. The context in which a user receives a coach's efforts to change behaviour or assist in keeping up the adoption of recently learned behaviour can have a large influence on the effectiveness of the coaching. If used correctly this information can be used to, for example, tailor timing, content, and representation (Op den Akker, Jones, & Hermens, 2014).

If we reflect on the behaviour change theories described in Section 3.1, we can identify multiple manners in which the external factors can have an effect. Stimuli or triggers might be present in the environment. A user might, for example, have the intention to eat healthy and keep to a diet, but it would be harder to stick to those intentions when confronted with a piece of cake. However, if the user would then notice delicious vegetable snacks sitting right next to the cake, it would make sticking to their intentions easier again.

Someone's social situation is also important to consider with regards to their behaviour. (Martire & Franks, 2014) note that social connections and the quality of these connections are important for our physical health. They found two common themes in recent literature on social connections and adult health. The first theme they mention is that connections and interactions with close others likely improve or worsen health by shaping the health behaviour choices people make. For example, if you want to change your behaviour and your family and friends keep offering you unhealthy snacks or try to convince you to sit on the couch and watch television instead of going to exercise, it will take more strength and determination to actually live healthily compared to a situation in which they would motivate you to go to the gym. Having social support from relatives, friends, or colleges can lower the barrier for actually

performing the intended behaviour. The second theme they mention is that there are risks associated with a shrinking social network in adulthood. For example, a fight with one of the few people still close to you, or losing one of the last people close to you can take a larger toll on you emotionally compared to when you have a larger social network and the stress worsens your health. The lack of a social network when suffering from an illness could also make it harder to deal with your health issues than it would be with a larger network supporting you. You can imagine that these sorts of factors can change your behaviour. For example, nobody has time to drive you to the gym and you can no longer drive a car there so you stay home and watch television instead, or you are having a hard time dealing with the stress of losing someone and end up eating a large piece of chocolate in an attempt to comfort yourself.

Another big influence is the user's where and the when. One might feel they are less able to perform the desired behaviour because of where they are and might even be annoyed by the suggestion to do so. For example, being at work does not seem like the correct timing to go exercise. The time at which the coaching is provided could also not be ideal. For example, being at work when your coach suggests you should go work out is not convenient, and getting a message to go to do some push-ups in the living room at 3 AM also does not seem workable for many people. In short, users will have preferences for when they are available for coaching and have time to listen. The study by (Klaassen, Op den Akker, Lavrysen, & Van Wissen, 2013) shows that preferences for the where and when of coaching can differ based on user characteristics as well. Thus, there will naturally be differences in preferences between user groups, as well as individuals.

(Oinas-Kukkonen & Hajumaa, 2009) recognise social influences as an important factor in their PSD Model and they also name 'technology context' as an important influence. They stress that the strengths and weaknesses of the information technology that is used should be thoroughly understood. The previously mentioned study by Klaassen et al. (2013) considered the strengths and weaknesses of different devices (information technology), such as portability (availability on the go) and the modalities in which they could provide feedback. They showed that different users preferred different devices for their feedback at different times. This shows that the strengths and weaknesses of these devices are of importance to the user, and should be understood and considered when one tries to coach a user. On top of that, it shows that there is an interaction between the strengths and weaknesses of an information technology and the rest of the context a user is in, as well as personal factors.

To summarize, the provided coaching can be made more effective when taking the context of the user into account. By providing personalised coaching, not only based on the user's features, but also on their context, the negative effect of context might be limited and the context can even be leveraged to improve the effectiveness of coaching.

3.5.2 Tailoring

Another essential component in designing a coaching system is Tailoring. Performing tailoring, which op den Akker et al. (2014) describe as 'The process of adjusting the system's behaviour to individuals in a specific context.' is an essential component to include when designing and providing effective coaching. Oinas-Kukkonen & Hajumaa (2009) name tailoring as an important Primary Task Support principle that will make information provided by the system more persuasive. As described in the previous section, context can have a large influence on the effect of coaching and on the behaviour performed by the coached individual. The elements present in the context of a user can be leveraged for tailoring information. Op den Akker et al. (2014) defined a tailoring model (see also Figure 19), in which they include seven tailoring concepts, in the context of physical activity coaching, which are the following:

- Feedback. Providing information about the individual's performance.
- Inter-human interaction. Any type of social support that is built in to a coaching system.

- Adaptation. For example, sending different messages for people with different motivations.
- User targeting (often meant when people use the term 'personalisation'). Attempting to increase or motivate users by suggesting or stating that the information is specifically for you.
- Goal-setting. As described in Section 3.1.7, setting a goal makes the execution of that goal more likely. This needs to be combined with feedback.
- Context awareness. Awareness of any information, non-critical to the application's main functioning, that can be used to tailor the system to the user.
- Self-learning. A system that is able to change with the user can tailor its actions better.

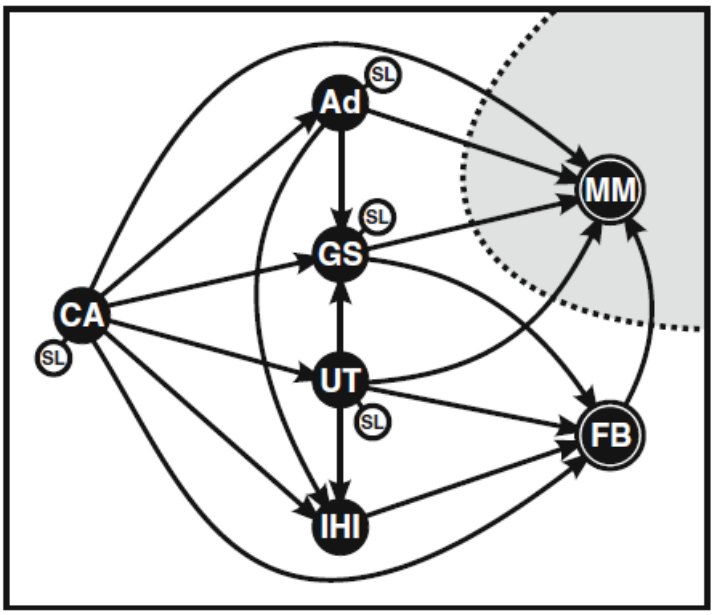

Figure 19: The tailoring model by Op den Akker et al. (2014) (taken from (Op den Akker, Jones, & Hermens, 2014)). The abbreviations reference the following: feedback (FB), motivational messages (MM) – which is not a tailoring concept but a representation resulting from the process – context awareness (CA), goal-setting (GS), inter-human interaction (IHI), adaptation (Ad), user targeting (UT), and self-learning (SL).

As shown in Figure 19 using the arrows, there are many possibilities to combine these concepts to improve coaching. A few examples given in the article would be to adjust a daily or weekly goal to the agenda of the user (CA → GS), make the goals specific to the user by using a user specific parameter such as their BMI (UT → GS), and adjusting the kind of feedback for the user to their context by, for example, sending them a text message instead of an audio message if they are in a public setting (CA → FB). If you are interested in more example of how to combine these concepts, we refer you to their article.

We can also apply this model to our context examples from Section 3.5.1. For our environment triggers example: when the user is going to a party and this is in their agenda, the coaching system could advise the user to contact the organizer of the party to let them know they are on a diet (CA → IHI). Even when at the party, the coach might send a timely message when they arrive reminding them of their health goal and telling them they trust the user will be able to get through the evening without touching any cake (CA → MM). For our example of social context: the system could learn which friends are good influences and which are bad ones in relation to the user's goals, and try to talk to the user about setting up a discussion between the user and these friends to resolve this issue (CA → IHI), or make the goal less ambitious and instead have it go up in smaller increments to make it easier for the user to go step by step using their own willpower (CA → GS). For our example regarding the user's where and when: the system could know when the working hours of the user are based on their week schedule and figure out

their sleep schedule. It could then make sure that the messages it sends to motivate the user to work out do not come in during those times, and instead only during free time of the user (CA → MM).

Another important and specific part of context is, as discussed in Section 3.5.1, the technology context. Klaassen et al. (2013) discuss how tailoring the information technology (device) to the context can be of importance, as users might have different options and preferences based on this context. Furthermore, (Kuylk, Op den Akker, Klaassen, & Van Gemert-Pijnen, 2014) argue that by having a system that uses multiple devices, the timing of messages as well as the content of these messages can be better tailored to the user. For example, a more elaborate coaching session discussing pros and cons could be had using a laptop at home which can use both audio as well as expressive animated embodied conversational coaches. On the other hand, simple updates on achieving the user's daily goal could be sent through text on the phone at convenient times to read them such as short text messages regarding calorie intake goals popping up on their phone before lunch time or a little bit before the user is going to cook dinner. This less elaborate, repeated and more text-based feedback at exactly the right time on the phone would be more glanceable than having an embodied conversational coach speak to the user, which according to (Klaassen, Op den Akker, & Op den Akker, 2013) is better suited for these kinds of messages. In conclusion, the different information technologies have different strengths and weaknesses that should be accounted for when communicating with the user.

As mentioned by Op den Akker et al. (2014), self-learning is one of the keys to a coaching system as it makes it able to better tailor to the specific user using it, instead of making more general assumptions about the user. Some of the possibilities for application of self-learning are discussed in (Op den Akker & Klaassen, 2013). They talk about using sensor data to give a coaching system additional context and make its algorithms more accurate. This could help to adapt goals to what is challenging for a specific user, such as making the step count goal lower for someone who has leg pains and therefore cannot walk as far as the average user. Another way to adapt to the user by self-learning is to observe the response of the user to the timing and context of messages and try to adjust the context and timing of future messages based on this response. For example, if the user frowns and instantly swipes away a message by the coach in the middle of the day during a meeting, the system could conclude that this might not be the right time and context. This could be based on the time of day and the location of the user (the office, using geolocation). The next time, the system would remember that during work hours when at the office, the user does not want to be bothered and wait for them to be on their way home before messaging them. The system could also learn to speak in a way more suited to the user by building up a psychological construct of the user and their environment as well as their use of language and try to adapt to this using natural language generation. Another way self-learning could be applied is to have the system learn what the best ways are to persuade a user and that knows when to 'give up' on persuasion when it cannot convince the user with the arguments it has. This can be done by building up an idea of what the user agrees and disagrees with, and selecting arguments later on based on this. The effectiveness of this approach was shown by (Andrews, Manandhar, & De Boni, 2008). They found that using a self-learning system was more persuasive than a task-oriented system, while not being perceived as more persuasive by users. They postulated that this might be because people did not feel coerced by the system as it gave up on persuading them when it concluded they could not be persuaded with its arguments. As can be seen from the previous examples, self-learning is an important part of tailoring that can be applied to many different parts of the interaction with the user.

To summarize, tailoring of coaching can make a large difference in coaching systems by making them more engaging, persuasive and effective as well as decreasing annoyances to the user such as getting coaching messages in the middle of a meeting. There are many aspects which a system can tailor, all with their own advantages. Some of the key concepts to tailoring are feedback, inter-human interaction,

adaption, user targeting, goal-setting, context awareness (including technology context) and self-learning.

3.5.3 Delivery Style and Politeness

Once the coaching system has an idea of what it wants to convey and why, knows the context (including technology context) it is doing it in and has done tailoring for it, and knows the user (including their current state) and has tailored to them, it is time to actually deliver its message. In the PSD Model, one of the main design feature groups is Dialogue Support, for which it is stressed that it is important to keep users moving towards their goal or target behaviour. The importance of how a system delivers its message cannot be understated. If the delivery is boring and samey, the user might end up not listening. If a coach comes off as rude, the user might decide to stop using the system altogether. This is why delivery style and politeness are important factors to consider.

For a start, (Baylor, 2011) notes that agents that want to motivate a user should be able to express their emotions, and do so at the right time. Furthermore, they postulate that when an agent speaks their voice should be as human-like in tone and prosody as possible. This is not all there is to it though. When a coach tries to convince the user, they will mostly use persuasive dialogue. Although this could be effective, it raises questions about whether the user will want to continue interacting with the system in the long term if all it does is try to persuade them. This is where some interesting ideas come from (Bickmore & Picard, 2005). They stress the importance of relational behaviours during the interaction. This includes things such as using humour in the interaction, using appropriate greetings and farewells, talking about mutual knowledge, emphasizing commonalities and de-emphasizing differences, as well as slowly disclosing more about oneself as the other does as well (reciprocal deepening self-disclosure), among other things. They found that users felt their working relationship (more liking, trust, respect) was better with an animated exercise agent using these relational behaviours than with a non-relational one. This shows the importance of a system not just delivering the required message, but also delivering it in the right way and mixing in some relationship building if one wants to continue interacting with the user.

One way to immediately ruin an interaction would be to come off as rude. Therefore, it is important to be as polite as necessary. To further delve into politeness in embodied conversational agents, we first need to discuss the politeness theory by Brown and Levinson as cited in (Glas & Pelachaud, 2014). This theory is about saving public self-image, also known as 'face'. Face consists of negative face and positive face. Negative face is the want of people for their actions to be unimpeded by others, and positive face is the want of people for their actions to be desirable to at least some others. According to this theory some acts intrinsically threaten the addressee's face, and they call these acts Face-Threatening Acts (FTAs). These can be divided in acts threatening positive face (for example, criticism, disagreements, et cetera) and acts threatening negative face (e.g. orders, suggestions, et cetera). A speaker can try to limit the face-threat of their acts by using several strategies. Ordered from most likely to be threatening to least likely to be threatening these strategies are: boldly, positive politeness (adding a positive spin to the FTA, such as being optimistic or giving reasons), negative politeness (trying to make the FTA smaller, such as apologizing or being conveniently indirect), off record (such as understating, or overgeneralizing) and not doing the FTA.

Several studies have been inspired by the politeness theory to try and see whether politeness has any impact on interactions between embodied conversational agents and the user. Confirmation of the theory holding for embodied conversational agents was found in a study by (Mayer, Johnson, Shaw, & Sandhu, 2006). Interestingly, they found that the expected pattern of results was stronger for participants with comparatively lower computing experience. This plays into possible self-learning and tailoring options yet again. In the previously mentioned article by Glas and Pelachaud (2014) they looked at the

relation between user engagement and the politeness of the agent. They postulated that the less engaged a user is, the more important it is for an agent to be polite. It is important to mention that both these studies mentioned that politeness is subjective. This also points towards opportunities for self-learning and tailoring by the system.

Finally, (De Jong, Theune, & Hofs, 2008) discuss another part of delivery style that is important to mention. This is the importance of alignment in a dialogue. They state that this can help give an agent a recognizable personality, increase their believability and even make them appear more socially intelligent. In their study, the authors of this article took a look at alignment of politeness, and similarly to the work we just discussed found that preferred politeness showed signs of depending on personal preference instead of being universal.

In conclusion, what exactly is said and how it is said can have a large impact on the stance of the user towards an embodied conversational agent. Of the many ways an interaction can be shaped, only some were discussed here. Some important takeaways are the importance of the proper expression of emotions by the agent, relational behaviours such as the use of humour, being as polite as the specific user likes, and last but not least to try and align the utterances and behaviour of embodied conversational agents during dialogue.

3.5.4 Dialogue Structure

It is all well and good that the system wants to convey something and has an idea how to deliver the message in the right way, but how does it manage a live dialogue with a user? It needs to understand to some extent, for example, what the user is communicating, who has the speaking turn, whether a user is asking or stating something, if the coaching system should apologize for hurting the user's feelings, the difference between an agent asking for something and demanding something, and more. This brings us to dialogue structure. A dialogue consists of many utterances with their own functions, or speech acts. These are built up from dialogue acts, which are the building blocks that help a system structure dialogues with the user.

The concept of dialogue acts is widespread among systems that have spoken dialogue interactions with the user. Many factors influence which acts there are and, as opinions have differed over the years, many different dialogue act taxonomies and inventories have been proposed. For some examples of dialogue acts, we look at the extended version of the Dynamic Interpretation Theory (DIT++) taxonomy as discussed in (Bunt, 2011). They discuss ten dimensions in which communicative functions and dialogue acts can exist. A few examples are turn management (dialogue acts concerned with grabbing, keeping, giving or accepting the speaker role), task/activity (dialogue acts for performing the task or activity underlying the dialogue), and social obligations management (dialogue acts for social conventions such as greetings, expressions of gratitude and apologies). Each of these dimensions has its own communicative functions and dialogue acts, although some dialogue acts can be used in several dimensions. An example of a dialogue act that could be used in any dimension is a question, although it would be used slightly different depending on which dimension it is in. In the turn management dimension, it might be asking for the turn, whereas in the social obligations management dimension it might be asking how the user's day was.

Whether an agent system needs a certain functions and set of corresponding acts depends on what kind of interactions the system needs to be able to have. For example, a simple system that has a dialogue with a user about which coffee they want might not necessarily need to be fully aware of the social context and would not need to understand the concept of showing gratitude. However, a system that is supposed to try and bond with the user and socially support them might have more use for such functions to help build a relationship. Simply said, considering what kind of dialogue acts a system needs to incorporate in its dialogue structure before building it is important.

To summarize, a system makes sense of a talk with the user by structuring the interaction into dialogue acts. The kinds of dialogue acts the system needs to be able to distinguish depends on the settings in which the system will be used. We discussed some key dialogue acts to show the concept, but did not cover an exhaustive list as there are many different taxonomies and these are too much to cover at this stage. Also, dialogue acts are part of the Dialogue and Argumentation System, which is the focus of Work Package 5.

3.6 Conclusion

In this Section we have reviewed literature on behaviour change theories (Section 3.1), coaching methods (Section 3.2), and behaviour change techniques (Section 3.3). We have done this with the aim to discover how behaviour change works in users, to identify existing coaching strategies and to find out what the building blocks of coaching strategies are (behaviour change techniques). While reviewing, we have identified elements that are important in behaviour change (summarized in Section 3.4). We have also reviewed the importance of context and framing (Section 3.5) and how knowledge about these topics might be leveraged for a delivery of coaching strategies that is tailored to a user and will therefore benefit them as much as possible.

While creating this review, we have also identified three points of attention that should be kept in mind in the design process towards the final coaching strategies. The first involves keeping up the user's motivation while they are being coached. Motivation to use the system is essential for it to elicit long-term behaviour change. We believe that having a Council of Coaches that is tailored to each user will contribute to the engagement of the user with the system and will aid their motivation, but it is something to keep in mind.

Secondly, there is a large number of elements that can differ between users and their contexts, and which can be used for tailoring strategies (as summarized in Section 3.4 and Section 3.5). While these elements can improve coaching, they also increase complexity. Figuring out an ideal balance between the two will be important.

And finally, the ethics of providing coaching by technology. Creating realistic coaches that can provide effective tailored coaching inadvertently involves an ethical component. We are constantly aware of this and it is part of discussions on Responsible Research and Innovation, which is one of the topics assigned to Work Package 2.

The next Section for this deliverable will focus on the design of the Shared Knowledge Base, which in turn will be an essential component of the system for providing tailored coaching.

4 Knowledge Base

As was described in Section 2, the second objective of this deliverable is to present an initial design for the Shared Knowledge Base component. In this chapter we will provide background information on knowledge base design and implementation, and existing (state-of-the-art) knowledge bases in related fields. We will also present an overview of the use of knowledge in the frameworks that the Knowledge Base will be integrated with, and will provide an overview of existing open platforms and services that can be used in the implementation. This will be followed by the design considerations based on the literature and the features that are necessary for effective coaching (identified in the previous chapter on coaching strategies). Finally, we will present the initial design for the Shared Knowledge Base.

4.1 Background on Knowledge Bases

A knowledge base is a structure that represents knowledge (or information about 'the world'). A knowledge-based system is able to reason about its knowledge instead of just producing actions that are reflexes to the input (Russell & Norvig, 2010, p. 234). The difference between what we, for now, will call a (re)action system and a knowledge-based system can also be observed when comparing Figure 20 and Figure 21.

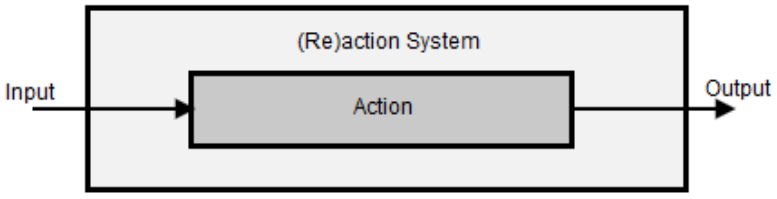

Figure 20: A (re)action system.

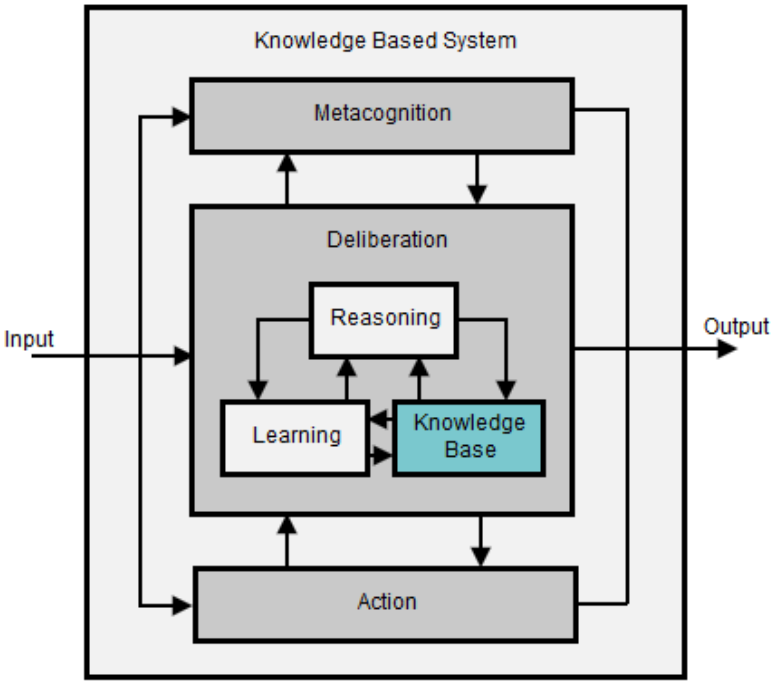

Figure 21: A knowledge-based system.

The knowledge in a knowledge base can include specific instances of the concepts that are represented in an ontology, although a knowledge base it is not required to be ontology-based. To give a simple example for a specific instance of a concept: one can know that there are apples, what you can do with them and how they are related to other objects in the world, but a specific apple is a specific instance of that concept.

4.1.1 Ontologies

There are two main definitions for 'ontology'. In philosophy, ontology is the study of 'what exists'. It involves dealing with questions such as 'What is a thing?' and 'What are the meanings of being?'. It also involves considering how things that exist can be categorized and in what manner they are related. This last aspect of ontology in philosophy is what comes closest to the other concept of ontology, namely ontologies as they are known in Artificial Intelligence, and having to do with knowledge bases.

In the context of knowledge bases, an ontology is a description of what objects and concepts exist in 'the world' and their relations. (Gruber, 2009) defines an ontology as 'an explicit specification of a conceptualization'. For example, consider the example ontology presented in Figure 22. A system that would have access to this ontology would know that 'a panda is a mammal', but it would also know that 'a zebra is a mammal'. Furthermore, it would know that 'a panda shares some similarities with a zebra' (which can be defined as aspects of the 'Mammal' concept). It could also infer that while a Blackbird is not a Mammal, it does share some similarities with a Panda and a Zebra since they are all Vertebrates.

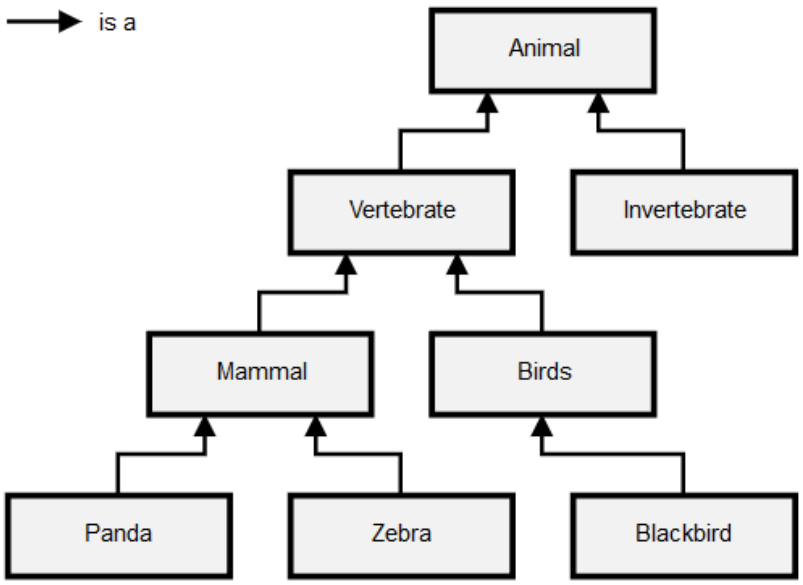

Figure 22: An example ontology for animal concepts with 'is a' relations.

4.1.1.1 Languages

There are multiple languages available for defining and processing ontologies. The most well-known (and those referenced in the section on example knowledge bases) are described in the following subsections.

4.1.1.1.1 Cyc Language (CycL)

CycL is the language used in the Cyc project (Lenat & Guha, 1991). It is not only used to define an ontology, but also the corresponding knowledge base. (See Section 4.1.2.1.1 for a description of the Cyc knowledge base itself.) In their paper describing CycL, (Lenat & Guha, 1991) declare that being able to express what is needed and being efficient are both important features of CycL and they state: *'Efficiency and expressiveness should not be traded off against each other, as both are essential. What has to be sacrificed is completeness'*. They also state that developing a knowledge base and its representation language should go hand in hand.

CycL began as a frame-based language and was an extension of the Representation Language Language (RLL). It has evolved since then in expressive power to Higher Order Logic. (Lenat & Guha, 1991) state that certain aspects of CycL differ from other approaches. They name the following examples:

- Argumentation-based default reasoning. In CycL you can refer to assumptions, not just to proven theorems.
- Modals. CycL can deal with, for example, believes and desires, instead of being limited to predicates.
- Reification[1] and reflection. CycL can reify and reflect on almost anything (for example, proposition, a micro theory or an inference mechanism).
- Special constructs. These allow the creators of CycL to, for example, express which concepts can be combined with other concepts without having to define a new predicate for each instance of a concept being combined with another concept.
- Entering a context. One can reason within a context without having to bother about unrelated contexts.

A detailed description of the syntax for the CycL language can be found on the Cyc website[2].

4.1.1.1.2 Resource Description Framework (RDF)

RDF is a framework for representing information on the Web (RDF Working Group, 2014). It is used by the Semantic Web (a knowledge base described further in Section 4.1.2.1.2) to represent connections between resources. Resources and predicates all have a URI/ IRI[3]. RDF uses triples to express connections between resources. Each triple has a subject, a predicate and an object, and corresponds to two nodes with a directed arc (see Figure 23).

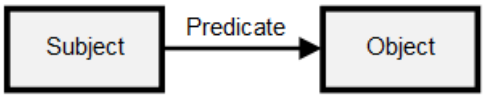

Figure 23: A RDF triple as a graph.

A simplified example triple could be (Dog, Attitude, Friendly), which would represent the relation that a Dog has a property called Attitude and that attitude has the value Friendly. Written down as RDF/XML this could take the form of what can be seen in Figure 24.

[1] Being able to express assertions about other assertions. For instance, in RDF a triple can be described as a Resource with subject, predicate and object properties, and then some.
[2] The CycL Syntax: http://www.cyc.com/cycl/syntax/
[3] Uniform Resource Identifier / Internationalized Resource Identifier. They are equivalent, IRI being a more modern version of URI.

RDF Schema (RDFS) is a set of classes that provide basic RDF concepts for the description of ontologies. Concepts represented are, for example, Friend of a Friend, Subclass Of, and Range.

```
01. <?xml version="1.0" encoding="UTF-8"?>
02.
03. <rdf:RDF
04.     xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
05.     xmlns:feature="http://www.example.com/animal-features#">
06.
07.     <rdf:Description rdf:about="http://www.example.com/animals#dog">
08.
09.         <feature:color rdf:resource="http://www.example.com/attitudes#friendly"/>
10.
11.     </rdf:Description>
12.
13. </rdf:RDF>
```

Figure 24: The (Dog, Attitude, Friendly)-example written down in RDF/XML.

RDF can be written down in different formats, the most popular being Terse RDF Triple Language (Turtle) syntax (Beckett, Berners-Lee, Prud'hommeaux, & Carothers, 2014). A collection of Resources linked together is known as a Graph.

4.1.1.1.3 Web Ontology Language (OWL)

OWL is a family of languages used for representing ontologies (McGuinness & Van Harmelen, 2004). In 2012 OWL 2 was introduced (OWL Working Group, 2012). OWL is a revision of the DAML+OIL web ontology language (and which we will not discuss any further), which was a thin layer upon RDFS. OWL had three sublanguages:

- OWL Lite (limited expressiveness, computational completeness)
- OWL DL (maximum expressiveness, computational completeness)
- OWL Full (maximum expressiveness, no computational guarantees)

OWL 2 has new syntax and new expressivity, and has three sublanguages (which in turn all have sublanguages on their own):

- OWL 2 EL (for use with very large ontological structures)
- OWL 2 QL (for use with many instances and a need for mainly query answering)
- OWL 2 RL (for scalable reasoning while keeping a reasonable amount of expressive power)

An example of OWL 2 written as OWL2/XML can be found in Figure 25.

```
01. <Ontology ontologyIRI="http://example.com/mammal.owl">
02.     <Prefix name="mammal" IRI="http://example.com/mammal#"/>
03.         <Declaration>
04.             <Class IRI="Mammal"/>
05.         </Declaration>
06. </Ontology>
```

Figure 25: An example (simplified) OWL 2 ontology for a Mammal concept written down in OWL2/XML.

OWL can be used to define objects and their properties, thus defining an ontology, but it can also be used to describe specific instances of those objects. OWL is also used in the construction of the Semantic Web (which will be discussed in Section 4.1.2.1.2). A well-known editor for OWL ontologies is Protégé (Musen, 2015). Reasoners for OWL include Pellet and HermiT.

4.1.1.1.4 Rule Interchange Format (RIF)

RIF is used to define and if necessary exchange rules for ontologies. These rules can be used when reasoning about the represented knowledge. There are multiple dialects of RIF that can be used to describe mechanisms for, for example, syntax specification, logic specifications, production rules, datatypes, functions and predicates.

4.1.1.1.5 SPARQL Protocol And RDF Query Language (SPARQL)

SPARQL is a query language for the RDF labelled graph data format (Harris & Seaborne, 2013). It can be used to search through data (SELECT returning bindings, and CONSTRUCT returning an RDF graph) using filters. A simple example query can be found in Figure 26.

```
01. SELECT ?node ?name
02.    WHERE{
03.       ?node <http://example.com/animalname> ?name .
04.    }
05. LIMIT 1
```

Figure 26: An example SPARQL query ('give me a node that has an animal name').

4.1.1.2 Ontologies for Behaviour Change Coaching

4.1.1.2.1 Behaviour Change in General

(Srivastava & Shu, 2014) designed an (OWL 2) ontology for behaviour change with the aim of making the existing literature on behaviour change more accessible. Their ontology has seven categories, which are:

- Problem types. A category divided into seven levels, which remind of the Stages of Change and the levels in the HAPA (see Sections 3.1.12 and 3.1.13), ranging from 'a new behaviour has to be learned' to 'a behaviour is being performed and needs support for maintaining' to 'a behaviour has to be stopped'.
- Barriers. A category describing all types of obstacles.
- Principles. Generalized approaches for behaviour change.
- Strategies. Are more specific than principles and describe how interventions are intended to affect behaviour (for example: warnings when users deviate from planned course of action).
- Mechanisms. Explanations for why strategies work or do not work.
- Applications. Examples of where behaviour change strategies have been used.
- Authors. Authors of the concepts.

4.1.1.2.2 Physical Activity Coaching

Example usages of ontologies in physical activity coaching ontologies are an ontology for the generation of personalised advisory messages (Erriquez & Grasso, 2008) and an ontology for motivational messages (Villalonga, et al., 2017).

(Erriquez & Grasso, 2008) based the composition of their applications advisory messages on the Transtheoretical Model of Change (see Section 3.1.12). Initially the best message for a situation was selected from a set of 500+ texts using constraint satisfaction techniques, but this was not a scalable process. They therefore decided to use an ontology based approach to improve it. They had access to the following information for personalisation purposes:

- Information collected through a habits and exercise questionnaire.
- Level of gratification for the working day.
- Perception of social relationships for the day.
- The weather.
- The mood for the day.

- How far the user has progressed in the programme.
- Possible causes of failure, as indicated by a user when relevant.

This information was initially represented as labels used for the constraint satisfaction. To start the ontology design process, they analysed the intention of the messages and categorized them into five intent categories:

- Comment messages. Consist of an assessment, a report and a 'trend'.
- Argument messages. Are aimed on influencing the user to improve their physical activity, and are personalised.
- Aid to introspection messages. Have as their aim to help the user understand the influences all components of his life have on each other.
- Suggestion messages. Provides personalised suggestions for increasing performance.
- Encouragement messages. Aim to show support and boost confidence.

They then created an 'Ontology of Discourse' to categorize and structure the messages. They also developed a user ontology, which was grounded on previous research (General User Model Ontology (GUMO)). The GUMO ontology involves statements that take the shape of, for example: (auxiliary='hasInterest', predicate='football', range='low-medium-high'), which could be used to define that someone has a medium interest in football. The user ontology defined by (Erriquez & Grasso, 2008) involved a number of dimensions, which included the following three that were related to:

- The user's beliefs
- The main features for the messages
- The activity program

Example high level classes would then be 'Beliefs Information', 'Interest Information', and 'Programme Information'. The system is able to reason about its knowledge, and, since it is ontology based, is able to 'explain' why a message is generated.

(Villalonga, et al., 2017) applied an (OWL 2) ontology based approach to model personalisable motivational messages for promoting healthy physical activity. They did not only model the message's intention and components, but also its contents. In their paper they describe their ontology in detail, so we will only give a short overview here.

The main class of the ontology is the Message class. A message can have various intentions, which leads to messages being classified as Neutral, Encourage, or Discourse messages. A message also has components that can for example relate to its purpose such as an Argument, Feedback, or Follow-up, but it can also have an Action, Time, Place or Element. They model many actions which in turn have subclasses and include an intensity value. Time can have the options: morning, afternoon, evening, and night. They also model many Places. Finally, Element represents animals, devices and manners of transport which can be required to perform an action.

(Villalonga, et al., 2017) continue to explain how the representation of specific messages can be constructed and how messages can be retrieved using SPARQL queries.

4.1.2 Examples of Knowledge Bases

In the following subsections we will describe some examples of existing knowledge bases. We will first discuss some general knowledge bases, that is, knowledge bases aiming to capture general knowledge. After that we will discuss knowledge bases for the more specific domains of health (behaviour) coaching (preferably to be included in an embodied conversational agent system).

4.1.2.1 General Knowledge Bases

4.1.2.1.1 Cyc

The vision for the Cyc (derived from encyclopaedia) project, that started in 1984, was to build a knowledge base that represents human common sense, and that can be used to solve the brittleness bottlenecks that can occur in AI systems due to gaps in their knowledge (Lenat & Guha, 1991). As stated by (Lenat, 1995): *'Cyc should be an expert system with a domain that spans all everyday objects and actions.'*. He also provides some examples of everyday knowledge that Cyc should have. To list two: *'If you cut a lump of peanut butter in half, each half is also a lump of peanut butter; but if you cut a table in half, neither half is a table.'* and *'You cannot remember events that have not happened yet.'*. As mentioned above (in Section 4.1.1.1.1) the language used to implement Cyc is CycL.

Since it is extremely difficult to build a consistent set of axioms covering everything, knowledge in Cyc is represented by microtheories (Lenat & Guha, 1991). Each microtheory covers its own domain and assumptions or levels of detail in different microtheories do not need to be identical (and may even contradict each other at some points). Assertions from multiple microtheories can still be combined when reasoning, but having the microtheory structure prevents the need to have one big knowledge base with decontextualized general axioms that are applicable in every context. There are thousands of microtheories (or contexts) that each consist of:

- A set of sentences that form the contents, that is assertions that are true in that context.
- An object describing the assumptions and simplifications for that microtheory.

Another challenge in knowledge representation is the representation of some form of certainty for a statement. Cyc does not use numeric certainty factors for each assertion (except in cases where statistics are known), but instead assumes each assertion as true by default, and it has meta-level assertions such as 'Assertion A is less likely than Assertion B' to cover certainty (Lenat, 1995).

The reasoning performed on Cyc is reasoning by argumentation, that is, not by logic or arithmetic, but by comparing pros and cons (Lenat, 1995).

4.1.2.1.2 The Semantic Web

The Semantic Web is an extension of the World Wide Web, for which the represented knowledge is not only readable by humans, but also usable by computers (Berners-Lee, Hendler, & Lassila, 2001). The ideology behind the Semantic Web is that knowledge representation should not be a centralized system where everyone has to share the same concepts, since such as system is not easily scalable. This also means that the level of detail and manner of representing differs between representations.

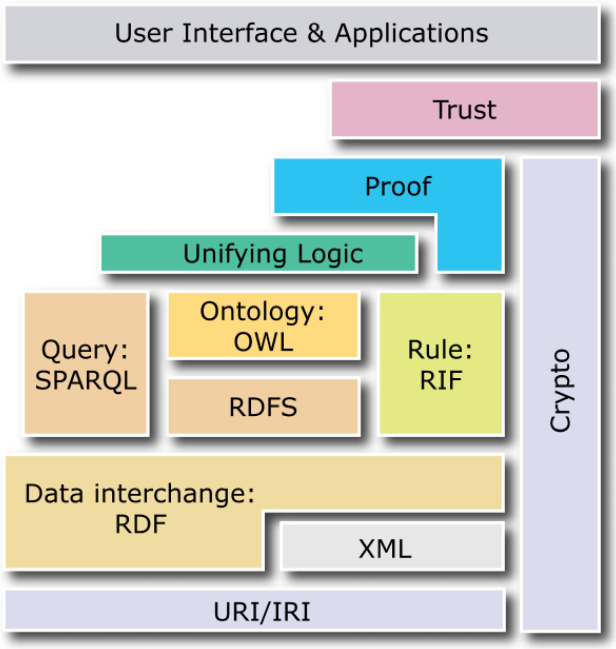

Figure 27: Layers in the Semantic Web. Taken from (Hawke, Herman, Archer, & Prud'hommeaux, 2013).

The structuring of the Semantic Web can be observed in Figure 27. Every item in the Semantic Web has a unique identifier (URI/IRI). Content within documents (web pages) can be structured using XML. The Semantic Web uses RDF to express relations between web pages. It also uses RDF, OWL, and RIF. Finally, SPARQL can be used to query the Semantic Web.

An example of a knowledge base using the Semantic Web technologies is DBPedia (Lehmann, et al., 2015). DBPedia is community project that extracts structured, multilingual knowledge from Wikipedia and makes that information freely available. In 2017, the English version of the DBPedia knowledge base described 4.58 million things (4.22 is limited to those classified in a consistent ontology) (DBPedia, 2018).

The underlying software implementation of a singular Semantic Web knowledge base is usually called a *Semantic Data Store*, or, because it is based on RDF at its core, also a *RDF Data Store* or *Triple Store*.

4.1.2.2 Knowledge Bases in Embodied Conversational Agents (Embodied Conversational Coaches)

(Bickmore, Schulman, & Sidner, 2011) designed a model for health counselling dialogues. Their framework included:

- A Theory model. Knowledge on the behaviour change theory and important concepts, theories and information on counselling.
- A User model. Knowledge on a specific user and their preferences.
- A Behaviour model. Knowledge on how behaviour change theories can be applied to specific behaviours.
- A Protocol model. Knowledge about a behaviour change intervention.
- A Task model. Knowledge on how the behaviour intervention can be executed.
- An External Data model. Data inputs for and outputs of the system.

In their paper they focus on the Task model, which is modelled task-independently. For example, it contains an Action, which then has three subconcepts: Therapeutic, Dialogue and Non-therapeutic. Another example is the Patient State, which has two subconcepts: Mental State (with subconcept Therapeutic Mental State) and Physical State. Their models have been based on theory from the

literature, which can be seen in, for example, the inclusion of the Processes of Change as subconcepts of Therapeutic Action.

(Bickmore, Schulman, & Sidner, 2011) tested their model in the domain of physical by including it in an embodied conversational agent (ECA). They also did a second experiment where they adjusted it to the domain of fruit and vegetable consumption. In doing so, they demonstrated that it is possible to create a more general representation that can be used to promote reuse for several health counselling domains.

4.2 Knowledge Bases in Existing Frameworks

The Knowledge Base in the Council of Coaches project will receive input from the Holistic Behaviour Analysis Framework, and will be connected to the dialogue and argumentation framework and the agent framework. Therefore, an important aspect in the development of the Knowledge Base is its integration with the other frameworks. In the following sections an overview of the use of Knowledge Bases in the existing systems will be provided. For the Holistic Behaviour Analysis Framework an initial description of the type of data that is collected, how this data is processed and the type of processed information that can be created (for example, detected behaviour or mental health condition) will be provided.

4.2.1 Knowledge Base – Behaviour Analysis

The recent technological advances in wearable technology enabled the release of wearable devices with powerful specifications and enormous sensing possibilities. As a result, there is ongoing research on healthcare applications using wearables, either smartphones or wrist-worn devices (for example, smartwatches), or a combination of these two. Despite the enormous sensing abilities that a smartphone can offer, there are some sensing modalities that require the sensors to be firmly attached to the body, making the smartwatches the optimal option. Additionally, smartwatches are used for monitoring physiological signals, such as heart rate, Galvanic Skin Response (GSR), respiration signals and skin temperature.

Hence, two of the most commonly used wearable devices, smartphones and smartwatches, have been used in healthcare research in order to collect clinical health data, monitor patient's vital signs and deliver comprehensive healthcare information to practitioners, researchers and patients, by enhancing the ability to diagnose and track diseases (Silva, Rodrigues, de la Torre Díez, López-Coronado, & Saleem, 2015). Specifically, the sensing modalities of a wearable device can lead to the human behaviour understanding by detecting short-term and long-term behaviours. Thus, human behaviour understanding can be divided into four main categories, including physical activity, cognitive, emotional and social behaviour.

Short-term behaviour can be defined as physical, cognitive, emotional or social behaviour that last for a certain period of time (e.g. hours, days). On the other hand, long-term behaviour can be defined as the concatenation of short-term behaviours over a prolonged period of time (e.g. weeks, months). Consequently, long-term behaviours depend on the purpose of the application for behaviour monitoring, and can be related to clinical conditions or disorders. For instance, depression, which is defined as a mental disorder due to low mood, can be detected over a period of at least two weeks (American Psychiatric Association, 2013), where a person is continuously sad (short-term emotional behaviours over a longer period).

In order to detect human behaviour, data from different sensors have to be processed and analysed. Wearables' motion sensors, such as accelerometer and gyroscope, but also other sensors, such as GPS, Wi-Fi and Bluetooth (signal strength), have been used to detect the user's activity and movement (for example sitting, walking, running, eating or performing more complicated hand gestures) (Gravenhorst, et al., 2015). Additionally, data related to screen touch events and user's response time can be used to track short term cognitive states, such as attention and alertness (Torous, Kiang, Lorme, & Onnela, 2016).

Furthermore, phone calls and text messages can be used to monitor the user's social life (Frost, Doryab, Faurholt-Jepsen, Kessing, & Bardram, 2013), while audio and microphone signals (or physiological signals through smartwatches), combined with the user's physical activity, can be used to detect user's mood (boredom, happiness, anxiety, etc.) (Muaremi, Gravenhorst, Grünerbl, Arnrich, & Tröster, 2014) (Kamdar & Wu, 2016). On the other hand, the accurate prediction of short-term behaviours can lead to the monitoring and prediction of long-term behaviours. Thus, a combination of the aforementioned sensing modalities can reveal relevant determinants of health. For instance, short-term emotional states, such as sadness, that remain the same over a continuous period of time, can be used to detect a long-term mental state, such as depression (see also Figure 28). In Table 3, an abstract explanation of the different sensing modalities is presented.

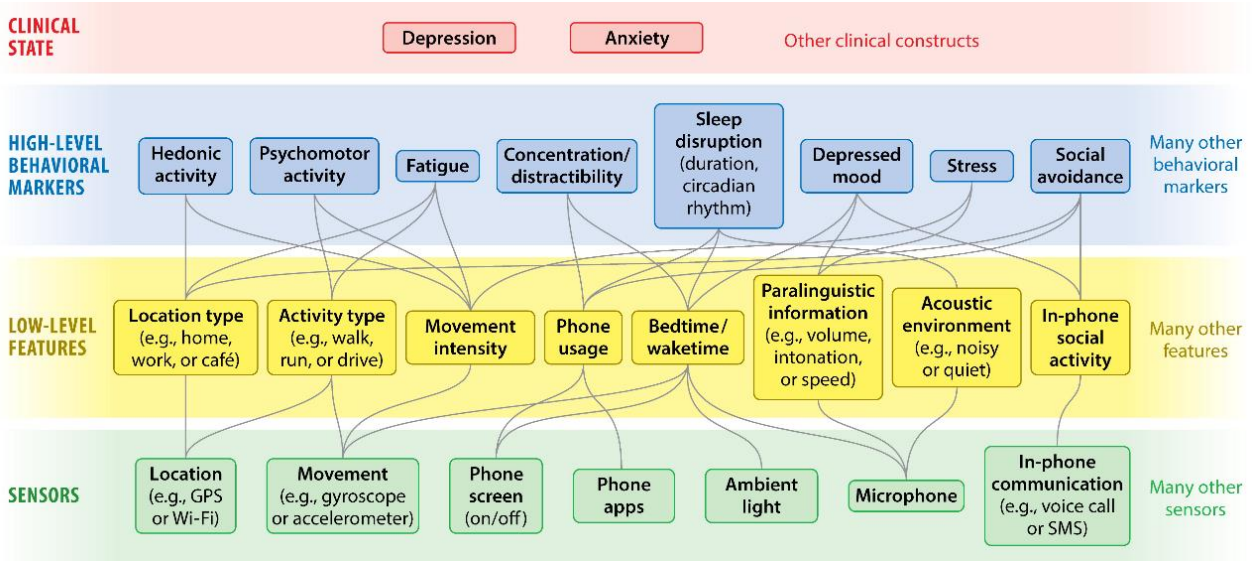

Figure 28: Illustration of a layered hierarchical sensemaking framework (Mohr, Zhang, & Schueller, 2017).

Wearable Device	Sensors	Features	Sensing Modality	Short-term Behaviours	Long-term Behaviours (*needs further investigation)
Smartphone & Smartwatch	Motion (e.g. accelerometer and/or gyroscope)	Time-domain (e.g. mean, variance, correlation) Frequency-domain (e.g. FFT components)	Physical Activity	Counting steps and/or simple physical activities (e.g. walking, sitting, standing) and/or complicated activities (e.g. shopping, eating, working) and/or gait analysis and/or fall detection and/or sleep duration and/or body balance and/or hand movements	Monitoring health and well-being and/or chronic diseases* (e.g. cardiovascular, stroke, rheumatoid arthritis, Parkinson disease, Diabetes)
Smartphone & Smartwatch	Outdoor Location (e.g. GPS)	amount of time spent outdoors, distances travelled, frequency of visited places, regularity of daily habits, etc.	Physical & Social Activity	Location detection and movement analysis and/or social interaction/isolation	Emotional – mental state, such as depression
	Indoor Location (e.g. Bluetooth, and/or Wi-Fi signals)	the amount and signal strength of visible Wi-Fi or Bluetooth stations			
Smartphone & Smartwatch	device usage patterns	speed of reaction time	Cognitive Activity	Alertness, attendance, fatigue assessment	Schizophrenia* and depression
Smartphone	SMS, phone calls, audio and microphone	Content, number of ingoing/outgoings calls and texts, etc.	Emotional & Social Activity	Emotional states and mood and/or social interaction/isolation	Emotional – mental state, such as depression
Smartwatch	Physiological signals (such as heart rate, GSR, skin temperature)	Time-domain (e.g. mean, variance) Frequency-domain (e.g. FFT components)	Cognitive & Emotional Activity	Emotional states and/or stress	Anxiety, sleep apnoea*

Table 3: An abstract explanation of the different sensing modalities.

4.2.2 Knowledge Base – Dialogue and Argumentation Framework

In the dialogue management systems developed at the University of Dundee, knowledge bases have been used as a means of providing beliefs to software agents that in turn allows them to participate in a dialogue, both with other agents and human users.

Two different knowledge base formats have been used - the Argument Interchange Format (AIF) and ASPIC+ (named after the project it historically originates from, the European ASPIC project).

4.2.2.1 AIF knowledge bases

4.2.2.1.1 The Argument Interchange Format (AIF)

The AIF was devised with the aim of developing a means of expressing argument that would provide a flexible, yet semantically rich, way of representing argumentation structures. It was put together to try and harmonise the strong formal tradition initiated to a large degree by (Dung, 1995), the natural language research described at Computational Models of Natural Argument (CMNA) workshops since 2001, and the multi-agent argumentation work that has emerged from the philosophy of (Walton & Krabbe, 1995), amongst others (e.g. (Reed & Rowe, Araucaria: software for argument analysis, diagramming and representation, 2004) (Parsons & Jennings, 1996) (McBurney & Parsons, 2002)). As originally specified, the AIF accounted only for monological argument; it has, however, subsequently been extended by (Reed, Wells, Devereux, & Rowe, 2008) into AIF+ and, as a work-in-progress, AIF 2.0 which both account for dialogical aspects of argument. Henceforth, where we refer to "the AIF" we mean "AIF+".

Central to the AIF core ontology are two types of node: Information- (I-) nodes and Scheme- (S-) nodes. I-nodes represent propositional information contained in an argument; a subset of I-nodes represent propositional information specifically about discourse events: these are Locution- (L-) nodes. S-nodes capture the application of *schemes*, which represent patterns of reasoning (RA-nodes), conflict (CA-nodes), preference (PA-nodes), illocution (YA-nodes), or dialogical transition (TA-nodes). Illocutionary schemes are patterns of communicative intentions (e.g. asserting, challenging, questioning etc.).

AIFdb[4] is a storage mechanism for AIF.

4.2.2.1.2 The AIF as a knowledge base

The rich structure provided by the AIF provides a strong basis from which to derive beliefs, especially where those agents are being used to represent previously-expressed opinions of real people.

AIFdb includes a mapping of *people* to *locutions* (L-nodes); that is, a record is maintained of who said what and when. Using this mapping in conjunction with a simple graph searching algorithm allows for the extraction of an AIF structure that models that person's beliefs, including structures of inference and conflict between individual propositions. This allows an agent to not only state that they believe some proposition, but also provide a reason for it if such an argument exists.

Consider the example AIF+ graph in Figure 29. Alice Jones has said 'r'. Bob Smith has argued against 'r' by saying 'p', and subsequently supported 'p' with 'q'. This graph can be used to model Bob Smith's knowledge base: he believes 'p', that 'q' is a reason for 'p', and that 'p' is conflict with 'r'.

[4]AIFdb: http://aifdb.org

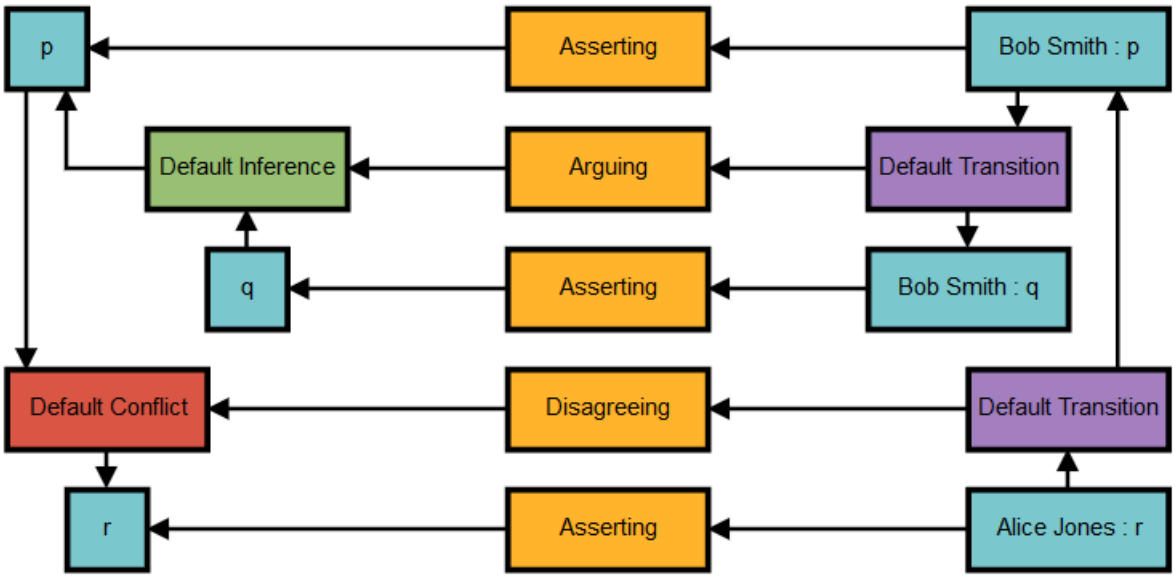

Figure 29: An example AIF+ graph.

4.2.2.2 ASPIC+ knowledge bases

4.2.2.2.1 Preliminaries: Abstract Argumentation Frameworks

Before describing the ASPIC+ theory and its use as a knowledge base, it is first essential to briefly introduce the concept of Abstract Argumentation Frameworks (AAFs). AAFs were first proposed by (Dung, 1995), where he abstracted argument into two concepts: *arguments* and a notion of *attack* between them. Arguments have no internal structure and the nature of attack is not defined. More formally, AAFs are defined as a directed graph, AAF = <Args, Atts> where Args is the set of arguments and Atts ⊆ (Args X Args); where an edge exists between two arguments, there is an attack between those arguments.

AAFs are evaluated under a number of different *acceptability semantics*. Informally, an argument is accepted if and only if any and all arguments (in the AAF) that attack it are not acceptable. Different semantics offer different determinations of acceptability ranging from highly skeptical to highly credulous.

4.2.2.2.2 The ASPIC+ framework

ASPIC+ is a system of structured argumentation that combines the work of (Pollock, 1987) on defeasible reasoning with that of (Vreeswijk, 1997) on structured argumentation. The result is a system of structured argumentation from which a Dung (1995)-style abstract framework can be obtained and subsequently evaluated for acceptability.

In an ASPIC+ system, information is, at a basic level, represented as propositions, strict and defeasible inference rules, and declarations of contrariness between propositions. Arguments are constructed recursively by first combining individual propositions with rules, then combining the conclusions of those arguments with rules, and so on until no more arguments are possible. An AAF is induced using these arguments, combined with the declarations of contrariness; this AAF can then be evaluated for acceptability.

4.2.2.2.3 ASPIC+ as a knowledge base

When using ASPIC+ as the basis for a knowledge base, the result of evaluating the indicted AAF is fed back into the system to determine the acceptability or otherwise of the original structured arguments and, by extension, the conclusions of those arguments. It is these "acceptable conclusions" that form the agent beliefs. For instance, if the argument [p, p=>q, q] were, at the abstract level, determined "acceptable", then q (as the conclusion) would also be rendered acceptable and thus the agent believes q.

Using ASPIC+ as a basis for a knowledge base provides similar advantages to using AIF, specifically that notions of conflict and inference can be expressed in the same knowledge base. An advantage of using ASPIC+ over AIF, however, is that it better supports argument dynamics: the process of updating arguments in the face of new information. If an agent receives (and accepts) some new information that conflicts with the previous beliefs, they can incorporate this information into their knowledge base and re-run the process of generating arguments, before obtaining an updated AAF with updated acceptability. Attempting this with an AIF knowledge base would present an apparent inconsistency, since the original (now conflicted) locutions remain ascribed to the agent that now accepts a contrary position.

4.2.3 Knowledge Base – Greta Platform

The Greta platform is a SAIBA compliant architecture. SAIBA is a common framework for the autonomous generation of multimodal communicative behaviour in Embodied Conversational Agents (ECA) (Kopp, et al., 2006). An overview of the SAIBA architecture can be found in Figure 30. To plan and realize behaviour a Behavior Lexicon is used. A Behavior Lexicon contains pairs of mappings from communicative intentions to multimodal signals.

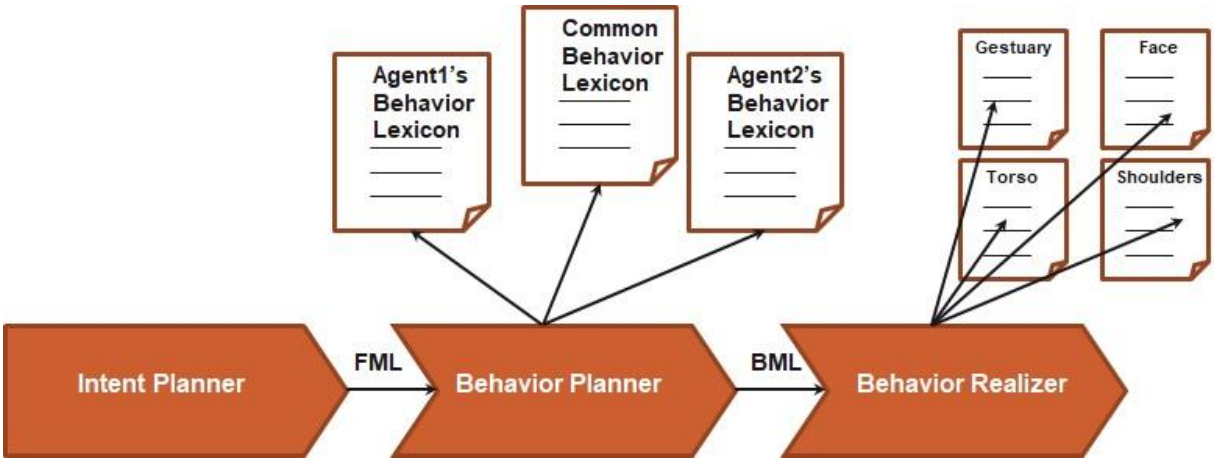

Figure 30: The SAIBA architecture indicating the Behaviour Lexicons and Libraries

The representation of communicative intents is done with the Function Markup Language (FML) (Heylen, Kopp, Marsella, Pelachaud, & Vilhjálmsson, 2008). FML describes communicative and expressive functions without any reference to physical behaviour, representing in essence what the agent's mind decides. It is meant to provide a semantic description that accounts for the aspects that are relevant and influential in the planning of verbal and nonverbal behaviour. Greta uses an FML specification named FML-APML and based on the Affective Presentation Markup Language (APML) introduced by (De Carolis, Pelachaud, Poggi, & Steedman, 2004). FML-APML tags encode the communicative intentions following the taxonomy defined by (Poggi, 2001), where a communicative function corresponds to a pair (meaning, signal). The meaning element is the communicative intent that the ECA aims to accomplish, whereas the

signal element indicates the multimodal behaviour exhibited in order to achieve the desired communicative intent.

The multimodal behaviours to express a given communicative function to achieve (e.g. facial expressions, gestures and postures) are described by the Behavior Markup Language (BML) (Kopp, et al., 2006) (Vilhjálmsson, et al., 2007).

Both these languages are described in length in Deliverable 6.1. In this deliverable we focus on describing the Behaviour Lexicon and its elements.

4.2.3.1 The Behaviour Lexicon

The Behaviour Lexicon can be extended with new behaviours if desired. All it takes is to specify the mapping between a new communicative intention and its multimodal behaviours.

There is a common Behaviour Lexicon for all embodied conversational agents. However, to capture specific behaviours for a given ECA, a behaviour lexicon can be attached to single ECA.

The elements of the Behaviour Lexicon define the mapping between communicative intentions and emotions with their multimodal expressions. They are represented by behaviour sets (for an example of some entries in the Behaviour Lexicon, see Figure 31). Each behaviour set contains a list of multimodal signals as well as the rules that explicit how the multimodal signals can be combined to convey an intention.

```
<?xml version="1.0" encoding="UTF-8"?>
<behaviorsets xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="../../Common/Data/xml/behaviorsets.xsd">
    <behaviorset name="performative-deny">

    <behaviorset name="performative-greet">

     <behaviorset name="performative-disagree">

    <behaviorset name="performative-inform">

    <behaviorset name="emotion-panic_fear">

    <behaviorset name="emotion-anxiety">

    <behaviorset name="emotion-sadness">

    <behaviorset name="emotion-pride">

    <behaviorset name="emotion-tension">

    <behaviorset name="emotion-relief">

    <behaviorset name="emotion-embarrassment">

    <behaviorset name="certainty-certain">

    <behaviorset name="turntaking-takethefloor">

    <behaviorset name="turntaking-givethefloor">
```

Figure 31: List of some of the entries in the Behaviour Lexicon.

4.2.3.2 Behaviour Sets

Behaviour sets are used to model the correspondence between the agent's communicative intention and its nonverbal behaviours. For example, to greet someone, the agent could raise the palm of its hand, showing a smile; to emphasize a word representing important information, it could produce a head nod, raising its eyebrows.

The definition of a behaviour set BS is a quadruple:

$$BS = (name; Sigs; Core; Implications)$$

in which:

- name: is the name of the behaviour set; it builds the one-to-one correspondence between the behaviour set and the communicative intention.
- Sigs: is a set of signals emitted on single modalities; this set represents the widest set of signals which can be used to convey the meaning specified in the parameter name of the behaviour set.
- Core: it is a subset of Sigs, representing those signals which have to appear in the multimodal signals communicating the given intention;
- Implications: it is a set of implication rules that allows conditionally constraining the presence of a signal of the Sigs set depending on the presence of the other signals.

The behaviour sets are defined with an XML-based representation language whose tags and attributes are the following:

- behaviour-set: this is the tag containing the behaviour set definition. It has the attribute
  - *name* that represents the name of the communicative intention the set is associated to.

  For example, the behaviour set in Figure 32 is automatically used when selecting the multimodal signal for communicating the intention of denying something.

```
01. <behavior-set name="performative-deny">
02.     ...
03. </behavior-set>
```

Figure 32: An example behaviour set for communicating the intention of denial.

- signals: this tag represents the set Sigs. It contains one or more signal tags, each one corresponding to a signal on a certain modality. Every signal has three attributes:
  - *id*, a unique id, used to refer to the signal inside the behavior set,
  - *name*, the symbolic name of the signal,
  - *modality*, the modality on which the signal is produced.

  For example, the behavior set in Figure 33 shows that the meaning deny is conveyed through one or a combination of the signals listed inside the signals tag. The given meaning can be conveyed with a combination of: shaking the head, moving the torso forward, producing a no gesture (index finger stretched up with the hand moving horizontally from left to right and vice-versa), frowning.

```
01. <behavior-set name="performative-deny">
02.     <signals>
03.         <signal id="s1" name="shake" modality="head"/>
04.         <signal id="s2" name="small forward" modality="torso"/>
05.         <signal id="s3" name="no" modality="gesture"/>
06.         <signal id="s4" name="frown" modality="face"/>
07.     </signals>
08. </behavior-set>
```

Figure 33: An example behaviour set containing multiple signals.

To allow introducing variability in the synthesized agent behaviour we can use indicate in the signal tag, as shown in Figure 34. The lines marked with a * specify that the signal identified by the id s2 can be either a no gesture (movement of the index finger from left to right and vice

versa) or a horizontal movement of the palm. This means that for the given meaning (to deny) these two signals are interchangeable on the gesture modality, with a probability of 50%, as specified in the alternative tag.

```
<behavior-set name="performative-deny">
   <signals>
      <signal id="s1" name="shake" modality="head"/>
      * <signal id="s2" name="no" modality="gesture">
      * <alternative name="horizontal palm" probability="0.50"/>
      * </signal>
   </signals>
</behavior-set>
```

Figure 34: An example behaviour set in which variability is introduced.

- constraints: it contains one *core* tag and one *rules* tag.
  - *core*: it represents the Core set and contains one or more item tags, each one referring to one of the signals listed in the signals tag, using the id attribute.
  - *rules*: it represents the Implications set and contains one or more implication tags.
  - *implication*: it contains a single element of the Implications set, that is, a rule that create a logical relation between the signals in Sigs.

Using the same example (see Figure 35), we may aim at specifying that in denying something, the head shake signal must (always and necessarily) be used. The lines marked with a * specify that the signal with id s1 (the head shake) must be used to communicate the denying communicative intention. In the behaviour sets syntax, all the *core* tags are contained inside a *constraints* tag.

```
<behavior-set name="performative-deny">
   <signals>
      <signal id="s1" name="shake" modality="head"/>
      <signal id="s2" name="small forward" modality="torso"/>
      <signal id="s3" name="no" modality="gesture"/>
      <signal id="s4" name="frown" modality="face"/>
   </signals>
   <constraints>
      * <core>
      * <item id="s1"/>
      * </core>
   </constraints>
</behavior-set>
```

Figure 35: An example behaviour set with a constraint specified.

Since some combinations of signals are not always possible, due to physical or other constraints, constraints on the possible combinations of signals in a behaviour set can be specified.

Going back to the same example, to "deny" something: there is a close eyes signal on the gaze modality; but this signal has to be produced separately from a shake signal on the head modality. That is if the eyes are closed, there is no head shake. But the reverse implication is not necessary. So, the agent can produce a head shake without necessarily closing the eyes. This example is represented by the code in Figure 36. The lines marked with a * are modelling the implication rule: "if the signal identified with the id s3 is selected for conveying the deny intention, then the signal identified with the id s1 must also be selected".

```
01. <behavior-set name="performative-deny">
02.    <signals>
03.       <signal id="s1" name="shake" modality="head"/>
04.       <signal id="s2" name="no" modality="gesture"/>
05.       <signal id="s3" name="close" modality="gaze"/>
06.       <signal id="s4" name="frown" modality="face"/>
07.    </signals>
08.    <constraints>
09.       <rules>
10.          * <implication>
11.          * <ifpresent id="3"/>
12.          * <thenpresent id="1"/>
13.          * </implication>
14.       </rules>
15.    </constraints>
16. </behavior-set>
```

Figure 36: An example behaviour set with an implication specified.

In the behaviour sets syntax, all the implication tags are contained inside a constraints tag and a rules tag. The constraints tag also contains the (optional) core tag. The rules tag contains an arbitrary number of implication tags. In the above example there is only one type of implication: "if signal A is selected, then signal B must be selected". There are a number of set of implications:

- if A then B: if signal A is selected, then signal B must be selected.
- if A then not B: if the signal A is selected for conveying a certain intention, then the signal B must not be selected. For example, to model that uncertainty can be conveyed by the production of either a gesture (rotating both hands with palm upwards, arms flexed at the elbows and opened sideways) or a head shake, it can be modelled with the two following implications:
  - if gesture then not head shake;
  - if head shake then not gesture.
- A if and only if B: this implication imposes the simultaneous presence of two (or more) signals: if one of the two is selected, the other one must be selected at the same time.

4.3 Existing Platforms and Services

The universAAL and FIWARE platforms are under study for integrating parts of the overall Council of Coaches system – at least some sensor devices or other applications. In this section, we will provide a short overview of what features from universAAL and FIWARE we can take advantage of in order to use them as a shared knowledge base, or assist in its developments.

4.3.1 UniversAAL

The universAAL[5] open platform and reference Specification for Ambient Assisted Living project is a project that has produced an open platform that provides a standardized approach to making Ambient Assisted Living solutions technically feasible and economically viable.

The component that plays the role of the knowledge base in the universAAL platform is the Context History Entrepot (CHE)[6]. This component's main feature is receiving every single message of contextual information (called Context Event) sent through universAAL's Context Bus and storing it in its underlying data store. These Context Events are built ontologically, so this underlying data store has to be a

[5] http://www.universaal.info/
[6] https://github.com/universAAL/context/wiki/Context-History-Entrepot

Semantic Data Store. The official implementation of CHE provided with universAAL uses Eclipse RDF4J[7] data store, although it is built modularly and other data stores can be connected, developing the necessary connector.

The Context Event messages sent through the Context Bus (and stored by the CHE) are push-based updates of the status of devices and applications. The CHE therefore holds a history of all the statuses and their changes. However, because the Context Events are ontology-based, the data store can merge all the stored information and compose a "snapshot" of the "current status" of all the data in the store. For instance, if an event arrives stating that user A is in location 1 and then another event says user A is in location 2, it is possible for CHE to infer that the current location of user A is location 2, while still being able to retrieve the past event of location 1. This is because Context Events are reifications of RDF triples, so even if the new data is "overwritten", the past event is still present in the data store. However, this feature has to be explicitly enabled in CHE, since it affects performance significantly, especially as the amount of data stored increases. This is a common problem in all semantic data stores.

All of this allows CHE to store and provide clients with both the current status of contextual information and the history of past events. It must be noted however that CHE itself only offers two types of services for clients to access these features. One is a collection of services where clients (through universAAL) can retrieve a collection of stored event according to some filters. The other, which can be used for retrieving current contextual status, is directly querying the underlying data store through SPARQL.

This is where other official modules of universAAL come into play: The Profile Server and the uSpace Server. Each of these interface with the CHE and use it as a more straightforward data store for two specific domains of information: User Profile data and uSpace data, respectively.

User Profile data represents the properties of users, their roles, personal information et cetera. The Profile server[8] provides explicit services for managing (storing, retrieving, modifying) this data. Clients can access these services through the universAAL platform for easier user data management.

The uSpace Server[9] plays exactly the same role, only for uSpace-related data. The uSpace is the name given to the logical space composed by all systems, applications and devices that can communicate through universAAL seamlessly. This could be for instance the house of an end user, but could also extend to his/her workplace, or mobile phone while outdoors. In other words, while the Profile Server manages user data, the uSpace Server manages data about the user's environment.

Both User and uSpace profile data models are defined by the Profiling ontology[10]. There are other modules offered by universAAL that also rely on the CHE and its stored data for their own purposes but those are already out of scope for the purpose of this document.

All of the universAAL software, including CHE, Profile Server, uSpace Server and ontologies, is provided as open source through the unrestrictive Apache License 2.0, and so does the RDF4J engine used in CHE.

4.3.2 FIWARE

The FIWARE[11] mission statement is: 'to build an open sustainable ecosystem around public, royalty-free and implementation driven software platform standards that will ease the development of new Smart Applications in multiple sectors.'

[7] http://rdf4j.org/
[8] https://github.com/universAAL/context/wiki/Profiling-Server
[9] https://github.com/universAAL/context/wiki/uSpace-Server
[10] https://github.com/universAAL/ontology/wiki/Profile
[11] https://www.fiware.org/

FIWARE is targeted at handling contextual data. The very core of the FIWARE platform is the Context Broker[12], whose official implementation is called ORION[13]. The basis of all interactions with the FIWARE platform is providing or consuming context information. Whether that's through one of the additional modules (called Generic Enablers) that provide additional features, or directly through its APIs, ORION Context Broker backs it all in the end.

ORION's underlying data store is a NoSQL database implemented in MongoDB. The core data model used to represent contextual data is Entities. Entities are the root of all context information, they are a data structure that has attributes with values, which is easy to represent and serialize using JSON.

The types of Entities and their possible attributes and values are defined by a collection of Data Model specifications by FIWARE[14], although new ones can be created. In addition to Entities, the Context Broker can also store other additional information needed for the operation of the system, like information about client subscriptions or the publishers of the information, but this can be considered metadata.

The context information in ORION Context Broker represents the current status of the Entities, not the past values. This is partly because FIWARE is intended to deal with a high volume of data, so storing only the current status of every value gives a better performance. All the context information is merged, regardless of the origin of that information. Therefore, if one sensor determines that location A has temperature 1 and then a different sensor determines temperature 2, it is the last one that will be currently stored (according to certain rules). This is achieved with the information that the providers (the ones giving the context information) give about themselves and their permissions.

It is possible however to keep track of previous values and historic information. There is another Generic Enabler, whose official implementation is called Cygnus[15], whose purpose is precisely storing all historic data, all the updates that the Context Broker receives and therefore the status of all entities in the past. Cygnus itself is just a connector that allows to store all this data in a number of different storage back ends: Hadoop, MySQL, MongoDB, Kafka or PostgreSQL.

The stored data can be queried by client applications, and there are other Generic Enablers provided by FIWARE that can perform additional functions over it, such as Big Data analysis (Cosmos) or Publishing (CKAN)

Each module implementation in FIWARE follows its own licensing strategy, but most are released as open source with the A-GPL v3 license. GPL licenses forces derivative works to also license under GPL, but the meaning of "derivative" work is usually contested when simply using the code, not modifying it. To make it clear, FIWARE states[16] that its licenses include a clause indicating that simply linking or using its software does not require to license under GPL. This clause may not be up to date in all their license notices, so it is best to proceed with caution when using a FIWARE module.

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[12] http://fiwaretourguide.readthedocs.io/en/latest/development-context-aware-applications/introduction/

[13] https://fiware-orion.readthedocs.io/en/master/

[14] https://www.fiware.org/developers/data-models/

[15] http://fiware-cygnus.readthedocs.io/en/latest/

[16] https://forge.fiware.org/plugins/mediawiki/wiki/fiware/index.php/FIWARE_Frequently_Asked_Questions_(FAQ)#I_have_found_that_some_FIWARE_GEris_are_distributed_under_GPL_or_AGPL_open_source_licenses_.E2.80.A6_Is_it_safe_for_me.3F

4.4 Design Considerations

There are many considerations that have to be taken into account in the design of the shared knowledge base. To start, there will be the requirements and user needs on which the deliverables in Work Package 2 will report. Then, there are the needs of the system components that will interact with and depend on the shared knowledge base. Other than these requirements that the shared knowledge base should fulfil there are design considerations that have a more practical (and perhaps idealistic) origins. In this section we will describe our considerations, which are in some cases based on assumptions about the specific connections between system components since the design of all components is currently ongoing.

4.4.1 Considerations for Assumed Interactions with Connected Frameworks

- The shared knowledge base should store the short term behaviours detected by the Holistic Behaviour Analysis Framework.
- The shared knowledge base should provide access for the Holistic Behaviour Analysis Framework to the knowledge about previously detected primitive behaviours.
- The shared knowledge base should store the long term behaviours detected by the Holistic Behaviour Analysis Framework.
- The shared knowledge base should provide access to the Dialogue and Argumentation Framework. In doing so the Dialogue and Argumentation Framework should be able to pose a query and the shared knowledge base should be able to return a meaningful answer.
- The shared knowledge base should update its knowledge (that is, add, change or delete) based on inputs by the Dialogue and Argumentation Framework.
- The shared knowledge base could include information on the personality and appearance of the coaches that would be required for their presentation using the Greta Framework.
- The shared knowledge base could include the behaviour sets that are currently used by the Greta Framework to convert intents into BML/FML specifications.

4.4.2 Considerations for Represented Knowledge

- The shared knowledge base should contain knowledge that will enable the embodied conversational coaches to have conversations with the user (broad, not coaching domain specific).
- The shared knowledge base should contain knowledge that will enable the embodied conversational coaches to tailor their coaching strategies to the user.
- For each embodied conversational coach, the shared knowledge base should contain knowledge that is specific for the domain of that embodied conversational coach.
- To emphasize: Since the groups of users included in the evaluation are Type 2 Diabetes, Chronic Pain and Age Related Impairments, these are the coaching domains for which knowledge should be included.

4.4.3 Considerations for Changing the Represented Knowledge

- It should be possible to remove or add new embodied conversational coaches to the system.
- Adding a new embodied conversational coach should include adding the domain knowledge for that coach and relevant specifications for their personality, appearance and behaviours.
- When a new embodied conversational coach is added, an addition to the general knowledge represented in the system should be made to enable the other embodied conversational coaches to join as a non-expert in a conversation with the user in the new embodied conversational coach's domain.
- When new knowledge is added to the shared knowledge base this new knowledge should be verified in terms of compliance with existing knowledge.

4.4.4 Considerations on Safety, Security, and Specifications

- Response/processing time should be real-time in order to not slow down other system components.
- Stored knowledge should be secure.
- The shared knowledge base will inevitably contain personal information and within that personal information possibly medical information (for example, that a user has Type 2 Diabetes). This knowledge should be treated carefully and should not be stored lightly (what is stored should be thought through). Further details on this topic will be provided in the Data Management Plan for Council of Coaches, but we are aware of its importance.

4.5 Initial Knowledge Base Design

In this Section we will present the initial design for the Shared Knowledge Base. This will be done in two parts. First, we will illustrate the connections the Shared Knowledge Base has to the other system components. Secondly, we will provide concept schematics of the models that Shared Knowledge Base can contain and we discuss the contents of these schematics in Subsections 4.5.2.1 to 4.5.2.4.

4.5.1 The Shared Knowledge Base in The Council of Coaches System

A schematic representation of how the Shared Knowledge Base could be expected to be placed in the overall Council of Coaches system can be found in Figure 37. Please note that this schematic includes assumptions on other components and that their correct design is presented in their corresponding deliverables. The schematic is merely meant to provide an insight on what in our view can be possible connections to and usages of the Shared Knowledge Base.

As can be seen, the connection with the Holistic Behaviour Analysis Framework (HBAF) will involve storing the detected behaviour (short-term and long-term) and providing access to previously measured behaviour. Other input from the HBAF might involve the detected presence of other people. The Dialogue and Argumentation Framework can be expected to require access to all stored knowledge, and it will have to be able to update and add to existing knowledge. The Greta platform will need input in either the form of Behaviour Lexicon information and personality features, which can be added to the intents that result from the Dialogue and Argumentation Framework, or it will receive BML/FML instructions from the Dialogue and Argumentation Framework, in which case the Dialogue and Argumentation Framework accesses the Behaviour Lexicon and personality features for the coaches.

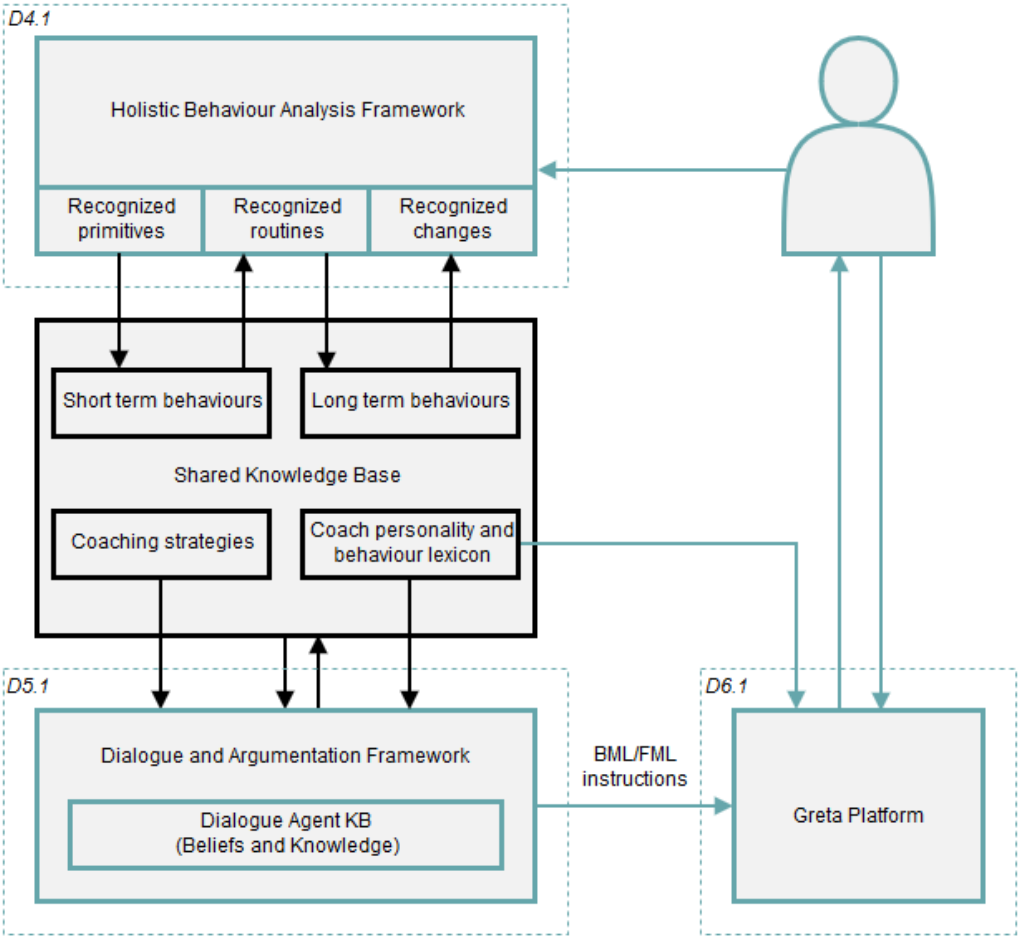

Figure 37: The Shared Knowledge Base within the Council of Coaches System architecture. Disclaimer: The representations of the Holistic Behaviour Analysis Framework, Dialogue and Argumentation Framework, and Greta Platform, and the connections between these platforms and the Shared Knowledge Base are based on assumptions. For an accurate description of the design of these components see Deliverable 4.1, 5.1, and 6.1, respectively.

4.5.2 The Shared Knowledge Base

In the following Subsections we will describe an initial design for how concept structures within the Shared Knowledge Base can be constructed. This design is influenced by the state-of-the-art, the foreseen interactions with the other system components and identified important elements for behaviour change coaching that we summarized in Section 3.4.

4.5.2.1 World Model

See Figure 38 for a schematic representation. The World model contains specific knowledge about the Council of Coaches system. There will be a possibility to add new modules to this model. This can, for example, be useful when a new coach is added to the system. The added knowledge in this model can then include basic knowledge about the domain of the new coach that will enable the existing coaches to join in conversations between the user and the new coach. The World model also includes general knowledge that might be relevant, but not Council of Coaches specific, to enable conversations with the user on 'off topic' topics. That is, topics that are not immediately coaching related, but which can be important in building a relationship with the user.

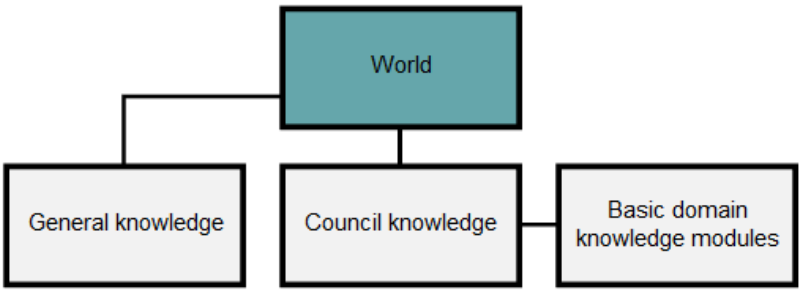

Figure 38: A schematic representation of what the World model can include.

4.5.2.2 Coaching Model

See Figure 39 for a schematic representation. The Coaching model includes knowledge about the coaching that can be performed by the system. That is, which coaches are available and what their capabilities and features are, but also which strategies are available to be applied by the coaches. Coaching strategies (that is, series of defined goals and steps to reach those goals in coaching, for example, showing compassion, but also applying behaviour change techniques) can be defined as general coaching strategies, which can be accessed and applied by all coaches. A coach has a domain, which involves knowledge about that domain and resources that the coach might want to reference (for example, a link to some extra information or a short movie showing an exercise). A coach can also have domain specific strategies which can serve as an addition to the general strategies. Furthermore, since the coaches each have their own personality, appearance and behavioural preferences, these features can also be included in the definition of a coach.

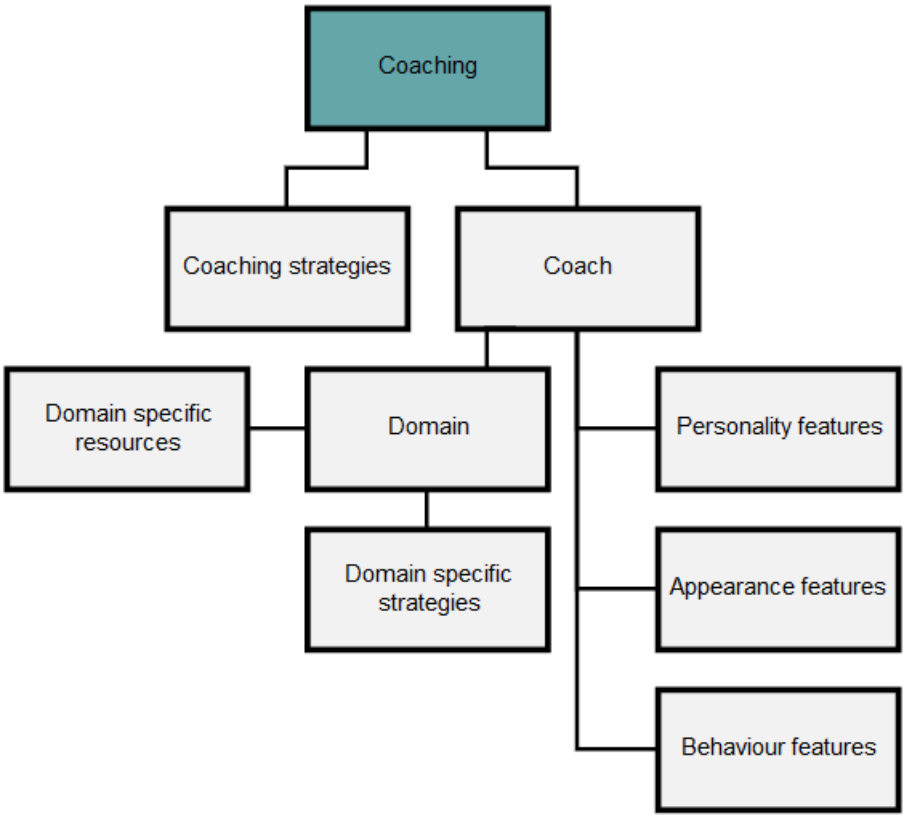

Figure 39: A schematic representation of what the Coaching model can include.

4.5.2.3 Context Model

See Figure 40 for a schematic representation. The Context model will include knowledge about the context in which the user is situated and in which the coaching will be applied. This can include a location and social situation, which can introduce certain triggers or barriers that the coach has to deal with. Other context elements can be added when relevant.

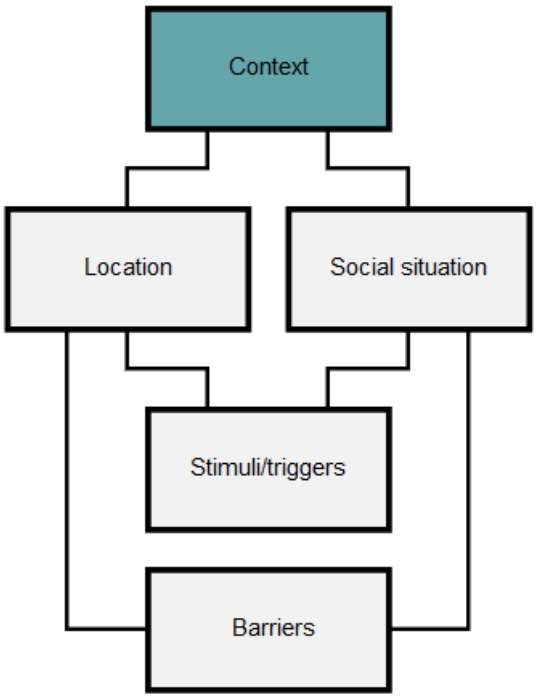

Figure 40: A schematic representation of what the Context model can include.

4.5.2.4 User Model

See Figure 41 for a schematic representation. The User model contains knowledge about the user. This involves basic information such as demographics, but also a representation of the user's internal state and external observations about the user. That is, to tailor coaching it will be useful to know what the user's goals are, what motivates him (for example, intrinsic or extrinsic motivation, or perhaps a-motivation). It is also good to know what the user's attitude towards his goals are and how this perhaps influences the achievability of these goals. Another important internal element of a user is their self-efficacy, which is based on their attitude towards goals and behavioural change, but is also based on their actual capabilities. Finally, the short and long-term behaviours that are detected by the Holistic Behaviour Analysis Framework can be represented.

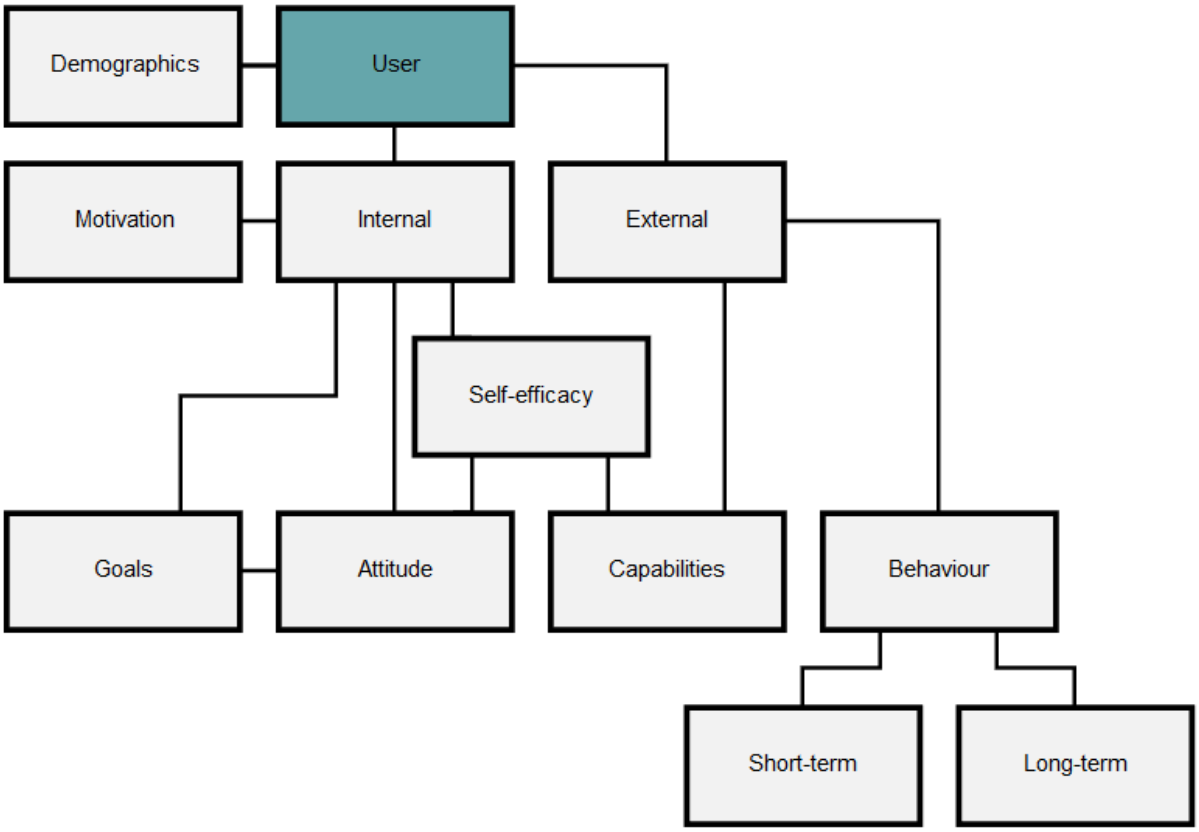

Figure 41: A schematic representation of what the User model can include.

4.6 Conclusion

In this Section we started by reviewing background information on knowledge bases. We described what their role and use in systems is and elaborated on ontologies and languages. Then we shortly described some existing ontologies for behaviour change coaching to provide an impression. We also gave some examples of existing knowledge bases. These reviews provided useful insights into what has been done and which considerations should be taken into account.

After the review we looked at the current versions of the platforms and frameworks that the Shared Knowledge Base will be connected to, that is, the Holistic Behaviour Analysis Framework, the Dialogue and Argumentation Framework and the Embodied Conversational Agent Platform, in an initial attempt to get an overview of what type of knowledge they would want to store and access. Following this, we presented two existing platforms that might be used in the implementation of the Shared Knowledge Base (universAAL and FIWARE).

In the Sections that followed we presented the design considerations that would be important for the development of the Shared Knowledge Base, and the initial design of the Shared Knowledge Base itself.

During the design process we have discovered some open issues that still need some clarification or a decision between Work Packages. We have listed these in the next, and final for this Deliverable, Section.

4.7 Open Issues

Below are the points of attention that we identified as in need of some clarification or a decision between Work Packages. We have formulated them as questions and named the Work Packages, which we think are suited to provide an answer or decision for each item.

- [WP4, 5, 6, 7] Will we use the universAAL or FIWARE platform, and if so, which one?
- [WP4, 5, 6, 7] API for the Shared Knowledge Base; Preferences?
- [WP4] Are routines included in the concept of long term behaviours? (That is, detection-wise, having a depression can be seen as a long term behaviour constructed of short term behaviours that identify as feeling sad and unhappy, while going to the gym every Friday at 8PM is not an almost continuously ongoing state, but an event that occurs regularly.
- [WP5, 6] Where are the exact dialogue contents generated? That is, intents and argumentation structures can be represented and processed without incorporating the specific sentence a coach should utter to a user. Where does it become actual English? (/Dutch/Danish)
- [WP5, 6] Will the behaviours sets the Greta framework uses be stored as part of the general information available for coaches (in the same manner that there are general strategies or parts of strategies that can be defined for all coaches, which can then be added to by defining coach specific strategies) so that they may be either accessed by the Dialogue and Argumentation Framework if that will produce not only the intents but also the corresponding BML/FML Greta requires, or by the Greta Framework if that's where intents will be transformed into BML/FML?
- [WP6] Will the information required for the coaches' personalities and appearances indeed be stored as part of 'a coach' in the shared knowledge base?

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