AUTOMATED TRAINING PLAN GENERATION FOR ATHLETES

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ABSTRACT

In sports, athletes need detailed and individualised training plans for maintaining and improving their skills in order to deliver their best performance in competitions.

This presents a considerable amount of effort and overhead for coaches, who not only have to set realistic objectives, but also formulate extremely detailed training plans. Automated Planning, which has already been successfully deployed in many real-world applications such as space exploration, robotics, or manufacturing processes, embodies a useful mechanism that can be exploited for generating training plans for athletes.

In this thesis, we propose the use of automated-planning techniques for generating individual physical preparation training plans, which consist of exercises the athlete has to perform during training, given the athlete's current performance, the period of time, and target performance that should be achieved. Our experimental analysis, which considers general training of kickboxers, shows that apart of considerable less planning time, training plans automatically generated by the proposed approach are more detailed and individualised than plans prepared manually by a coach.

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ABBREVIATIONS

ATP	Annual Training Plan
IPC	International Planning Competition
PDDL	Planning Domain Definition Language
PE	Performance evaluation

1. INTRODUCTION

In sport competitions, the primary purpose of athletes is to reach the best possible performance at that specific time. Therefore, athletes preparation and training plays a pivotal role. The key to achieve high-level performance in sports is dependent on the quality and of the timing of training: without proper training planning and a training plan execution, athletes cannot perform at their very best [1–3].

Training planning can be defined as a predictive process focused at rationally, systematically, and sequentially organising training units and the recovery process to achieve the desired performance results [4]. Planning and especially long-term planning in sports is an important topic, that has been the focus of extensive research. Even though training planning is a well-studied area, the complexity and high demands on time resources still makes it an overwhelming process, as it is performed manually [4, 5]. Due to this, only a limited number of professional coaches have the ability and resources to deliver training plans of the quality that would enable their athletes to perform on their very best level [3].

In order to deal with the complexity issues of generating training plans manually, this work investigates the exploitation of Automated Planning to assist coaches in designing effective individual training plans for athletes. Automated Planning is a research area which is a branch of Artificial Intelligence, and it can be viewed as the reasoning side of acting [6]. The purpose of Automated Planning is to find a partially or totally ordered sequences of actions that allows to transform the environment from a given initial state to a desired goal. Such sequence of actions are called plans. Plans can then be executed by artificial agents or by humans, which in our case are athletes [3]. To take advantage of Automated Panning, we designed a dedicated set of models that are used to automatically generate training plans, specific for the considered training period, which are primarily designated for developing athletes' physical skills to get them ready for competitions.

It is important to bear in mind that every sport has different requirements for athletes preparation and to be able to develop a single general domain that could satisfy all sports is not feasible. For that reason, there has been made a decision to choose a specific sport that serves as a proof of concept for our approach. Nonetheless, our goal is to deliver a blueprint planning model that can be used as for a wide range of physical sports, with small modifications, extensions and adjustments. As a case study, we designed the planning model for the kickboxing sport, and the reason behind this choice is that the author of this work has more than 14 years of experience as a top-level athlete and several years as an instructor. This provides therefore the ideal conditions for designing and assessing the proposed approach.

The use of automated planning comes a very natural choice, given the need to produce training plans that are sequences of ordered training "actions", and given the goal-oriented perspective of the process. Furthermore, Automated Planning enables us to define a single domain model, which can be used for all athletes training in a given sport, while individual needs and differences can be specified via a dedicated planning problem.

1.1 Motivation

In all sports, training planning is an essential part of athletes preparation, which requires significant time resources, extensive knowledge of the specific sport, and a deep understanding of athletes' performance and dynamics. Training planning is a complex process that differs according to sports and is influenced by a multitude of factors, which adds to the planning complexity [3]. These factors involve aspects such as athletes' predispositions, athletes' health conditions, competition goals, technical and tactical skills, etc. [7]. The complexity and the large number of variables, that have to be incorporated into the training planning, makes it a highly complicated process. As a consequence, as the process is mostly performed by human experts, it is often oversimplified or even abandoned altogether. Due to this, a typical training plan is often devised with limited resources and knowledge, and then reused for a number of athletes or a training group without taking into account the differences among athletes of the group. This is undesirable as such an approach can result in athletes underperforming. High quality individualised training plans, which is leveraging sports science knowledge, would enable athletes to perform at their best.

From above reasons we identified the following motivations for this research:

- to provide an automated approach for dealing with training planning, that leverages on sport science knowledge, and would support coaches in their planning efforts.
- to investigate the encoding of sport science knowledge in operational planning models.
- to investigate the ability of automated planning in producing high-quality plans for individual athletes that would support them in reaching their top-level performance.
- to design a consistent process of planning and plan evaluation that would enable to determine a training plan success or failure.

1.2 Contributions

This work contributes to the interdisciplinary application of automated planning for the generation of effective sport training plans. To the best of the author' knowledge, this is the first time that automated planning has been exploited in order to generate training plans for professional athletes.

The main contributions of this work can be summarised as follows.

- **Encoding of sport science knowledge and expertise into an operational planning domain model.** The proposed domain model represents a significant advancement in sports training planning, as it not only speeds up the planning process, but what is more, it generates plans that are supported by the sports science literature. Therefore, the approach has the capability to offer highly individualised plans that incorporates the best practice of the field.

- **Identification and definition of physical attributes that are used to characterise the state of an athlete**. These physical attributes are essential for our planning model as it provides us insight into physical performance and bases for defining actions, effects, and initial and goal states.

- **Establishing testing approach, including testing battery and its evaluation, to determine athletes' performance.** This supplied us with an approach for acquiring athletes performance data that are used prior and during plan execution. Further, the testing approach enables us to determine the plan success or failure, in which case a re-planning is in order.

- **Formulation of quantification scheme that enables to transform athletes' testing results into a physical attribute value**. The need for this scheme comes from the fact that it was necessary to obtain values that would represent physical abilities. To the best of the authors knowledge there is not any similar method that would enable us to quantify and encode athletes physical abilities.

- **Validation and evaluation of the training plans**. The generated plans have been compared against hand made plans that has been provided by a professional coach, who has more than 20 years of experience, and who is a national coach for Czechia. The coach also validated and evaluated the plans as satisfactory.

This work represents the first principled investigation of the area, and it is understood that it may be useful to foster future work on this interdisciplinary topic. On the final note, preliminary domain model version has been published in a paper at SMC 2018 conference [3]. In the thesis, we extended the work by a customizable physical attributes increments, different attribute calculation, optimisation metrics, and more extensive experimental evaluation.

1.3 Thesis Overview

This thesis is organised as follows.

Chapter 2 provides the necessary background in terms of automated planning and sports science. With regards to automated planning, the topics covered include Classical planning, Numeral Planning, and Planning Domain Definition Language. The sport science part of the chapter focuses on describing athletes' physical abilities, sports performance, athletes' testing, kickboxing, and annual training planning. The physical abilities Chapter 2.2.1, deals with human body abilities that are the prerequisites to be able to perform any physical task. Further, the sports performance described in Chapter 2.2.3 and the physical abilities chapter introduce the body properties that have been used to define the domain model.

Chapter 3 introduces the encoded sport domain model, and the proposed quantification scheme. This chapter describes the designed encoding of athletes physical properties, in order to transform them into physical attributes that can be represented as the initial state of the automated training planning process. Further, this chapter includes sports planning domain model specification that includes an athlete's physical attributes representation, detailed description of domain model actions and their examples, and planning problem file descriptions.

Chapter 4 shows the results of the performed experimental evaluation, involving the case study of three athletes with different performance levels, comparison of hand made plans created by a domain expert with our plans, and expert validation of our planning approach and quality of the plans.

Finally, **Chapter 5** gives the conclusions, summarises the main results of the work, and highlights potential avenues for future work.

2. BACKGROUND

In order to perform automated training plan generation for athletes, it is essential to explore existing literature and provide the background for this research. This chapters provides the essential background on two subjects, namely automated planning and sports science.

The first section focuses on automated planning, and has three parts, which are classical planning, numerical planning, and planning domain definition language. The classical planning section 2.1.1 provides us with the basic subject knowledge that is needed for understanding the numeral planning on which the domain is built. The section 2.1.2 that deals with numerical planning, that is a child of the classical planning, and its expressing power. As the name suggests, the numerical planning expands the classical planning for the numerical aspects of the world without which is a necessary requirement for the research. To be able to transfer the research idea into a planning tool that will generate training plans, there was a need for a planning language that would enable us to do so.

The section 2.2 of the background is focused on the sports side of the research. It provides us with the necessary knowledge, which empowered us to collect requirements upon which the domain is developed. The chapter is divided into five parts, such as physical abilities, kickboxing, sports performance, athletes' testing, and annual training planning.

2.1 Automated Planning

Automated planning is a discipline of AI which can be looked at as a reasoning side of acting [6]. In other words, automated planning concentrates on the problem of finding ordered or partially-ordered sequence of actions that allows to transform the world from an initial state to a given required goal state.

Such a series of actions is called a plan. A produced plan can be performed by artificial entities or by humans.

Domain-Independent planning is desirable for the following reasons: a) Every planning form has some commonalities and can be unified by domain-independent planning. to understand the planning process there is a need for these commonalities investigation. The investigation of these commonalities is vital for understanding the process of planning and can contribute to the domain-specific approaches [6]. b) The cost can be reduced with the adaptation of general tools. c) Planning as AI research aims to design an autonomous intelligent machine, where domain-specific planning is limited to the specific area unless it can develop into new domains by interaction with its environment [6].

There is a need to mention that automated planning, in general, has difficulties with the expressivity of planning formalism, such as i) what input can be defined, ii) the definition compactness, iii) how consistently a produced plan can be expressed, etc. [8]. For that reason, a number of planning languages called action languages has been developed [9]. One of those languages is a language called planning domain definition language commonly referred to with its acronym PDDL, which is the planning community standard language used for representation and exchanging of planning domain models [10]. The PDDL is further discussed in section 2.1.3.

To solve specific planning problem by domain-independent planner there is a need to fetch to it problem specification and knowledge about its domain. Nowadays, a large collection of domain-independent planners and generic solvers exists. Further, each of them accepts planning problems and domains in some variation of action language such as PDDL generates a plan, a solution to the planning problem if it exists [10]. Accordingly, the planners can be interpreted as black-boxes, which in order to operate them it is required to produce a planning task description and after the output plan can be processed [3].

Automated planning is generally branched into several fields, according to the level of expressivity of the used language and the characteristics of the problems to be solved. Among the others, those fields that are relevant to this research are classical and numeral planning [11]. The next chapter deals with classical planning as it is the chosen planning method for this research. It will be followed by introducing numeral planning, planning formalism, and last but not least planning domain definition language (PDDL).

2.1.1 Classical Planning

Classical planning is a branch of automated planning, which belongs to the study field of AI. Automated planning, in general, is a discipline devoted to finding a sequence of actions which transfers the state of the world from some initial state to a defined goal state [6]. Generally, classical planning is referring to a *restricted state-transition system*, which can be understood as a system that typically adopts all eight relaxing assumptions described by Ghallab [6]. These relaxing assumptions of the classical planning domain models are as follows:

- The system is **finite** - the planning system has a finite number of states.
- The system is **fully observable** - there is a complete knowledge of each state of the system.
- The system is **deterministic** the system is deterministic if for every action applicable to a state the action transforms the system to a single another state.
- The system is **static** - the planning system is static if the system does not possess any internal dynamics. In other words, if the state resides the same until the controller exploits an action.
- The planner has **restricted goals** - the planner can accept only goals that are explicitly specified as a single state or a set multiple states. The aim is to find a sequence of state transitions that terminates at one of the goal states.
- The planning solution is a **sequential plan** - the planning problem solutions is a linearly ordered finite series of actions.
- Actions and events have **implicit time** - the actions do not reflect a measure of time. In other words, the actions do not have the duration and are instantaneous state transitions. This does not mean that time cannot be expressed it just means that the actions do not represent time explicitly.

- The planning can be done **offline** - the system and the planner are not affected by any changes that could occur while the system is planning. The planner is planning for the given initial and goal states without emphasis on the current dynamics.

These relaxing assumption are usually captured by the system name, which is deterministic, static, finite, and fully observable state-transition system with restricted goals and implicit time. This kind of system is presented as $\Pi = (S, A, \lambda)$. In the given triple S, A and λ are finite, where $S \times A \rightarrow S$ and $\lambda(s, a)$ is a state, which can be reached by application of a to s, if possible. A planning problem for the given planning system is described as a triple $P = (\Pi, s_0, g)$, where s_0 is some initial state and g expresses a single or set of goal states. The solution of the planning problem is an ordered sequence of actions $(a_1, ..., a_k)$ which are associated with sequence of state transitions from s_0, s_1 to s_k in a way $s_1 = \lambda(s_0, a_1)$ and $s_k = \lambda(s_{k-1,a_k})$, where s_k is a goal state [6].

Figure 2.1 shows an example of a DWR domain, which is commonly used to provide understanding of classical planning principle and to demonstrate various planning representations. Also, the figure 2.1 demonstrates the initial state s_0 of our planning scenario example.

The next step is to introduce a formal description of classical planning. There are three commonly used different but equivalent representations, which provide the same expressive power [6]. The three representations are:

(i) Set-theoretic representation represents various propositions about the world by a finite set of propositional symbols [12]. Further, each action specifies which propositions are associated with the state for the action to be applicable. Also, if the action is applicable it defines which propositions will be added and removed to transfer the world into a new state [6].

(ii) Classical representation defines states and action analogously with set-theoretic description, however, the difference lies in the usage of first-order literals and logical connectives instead of propositions. This is the most used representation for restricted state-transition systems [6].

(iii) State-variable representation represents each state as a tuple of values of n state variables such as $\{x_1, ..., x_n\}$. Actions are defined through a partial function that projects the tuple into other tuple of values of the n state variables [6].

The above representations can also be further extended in various ways. For example, one of the ways is to use logical axioms to describe assumptions about the states of the world. Another example can be the use of more general logical formulas to define the preconditions and effects of an action [6]. Across this work is used classical representation, which is the most popular choice for classical planning.

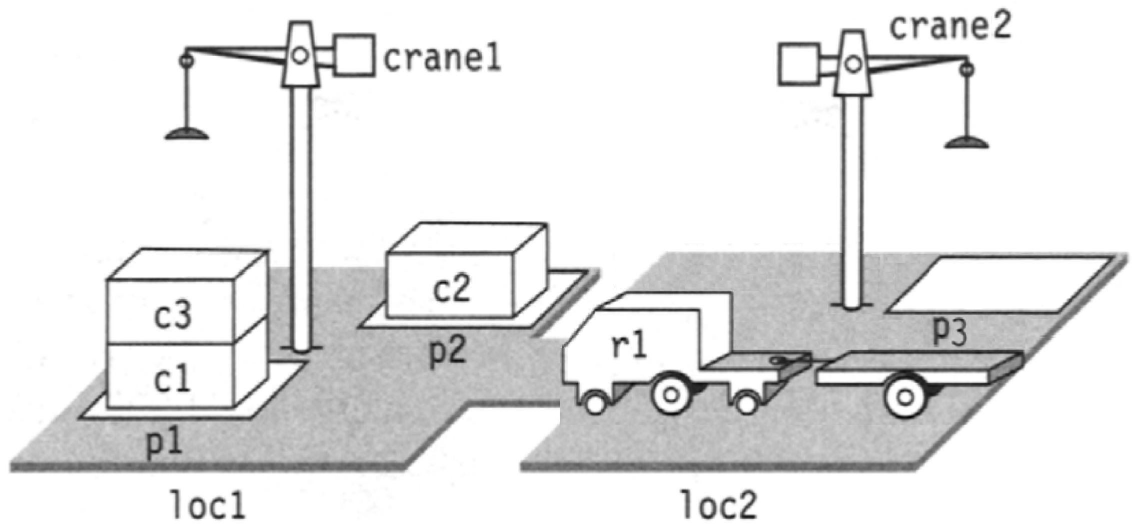

Fig. 2.1. The example of DWR's Initial state $s_0 = \{attached(p1, loc1), attached(p2, loc1), attached(p3, loc2), in(c1, p1), in(c3, p1), top(c3, p1), on(c3, c1), on(c1, pallet), in(c2, p2), top(c2, p2), on(c2, pallet), top(pallet, p3), belong(crane1, loc1), empty(crane1), belong(crane2, loc2), empty(crane2), adjecent(loc1, loc2), adjecent(loc2, loc1), at(r1, loc2), occupied(loc2), unloaded(r1)\}$

The classical representation is a generalisation of the set-theoretic scheme, which is done through adapting notation derived from first-order logic. In other words, the system states are defined as sets of logical atoms which can be with some interpretation determined true or false. Planning operators are modifiers that change the truth values of the atoms [6].

The next step is to introduce planning task, planning operators and a plan definitions, which are formed according to Chrpa, Vallati, McCluskey [13] and presented in Definitions 2.1, 2.2, and 2.3.

Definition 2.1. A planning task is a tuple $\Sigma = (Dom_\Sigma, Prob_\Sigma)$, where Dom_Σ represents planning domain model and $Prob_\Sigma$) represents the planning problem. The planning domain model consists of a finite set of predicates P_Σ and planning operators Ops_Σ exhibited by $Dom_\Sigma = (P_\Sigma, Ops_\Sigma)$. The planning problem $Prob_\Sigma = (Objs_\Sigma, I_\Sigma, G_\Sigma)$ is a triple composed of a finite set of objects $Objs_\Sigma$, an initial state I_Σ, and a goal G_Σ.

Let ats_Σ be a set of all atoms constructed by substituting the predicates' P_Σ arguments with the objects Obj_Σ. To put it differently, an atom is an instance of a predicate. Further, each state is a collection of atoms ats_Σ, although the initial state I_Σ is a distinguished state. The goal $G_\Sigma \subseteq ats_\Sigma$ is a set of atoms, and the goal state is any state which includes the goal.

It worth to mention that the above definition 2.1 promotes the full environment observability. This is demonstrated by the assumption that atoms belonging to s are true in s, where on the other hand, the atoms not residing in s are assumed to be false in s.

Planning operators are elements that modify the environment through their effects. The effects capture what is changed in the environment after the application of the operator. The effects are in the form of positive effects, which change the atoms to true, or negative effects that transforms the atoms to false. Further, the planning operators have to include preconditions that determine in what conditions the planning operator can be executed. These conditions have to be met prior to the operator application. It is important to note that *actions* are instances of planning operators. This means that objects substitute operators' variable symbols. Planning operators illustrate the types of activities that can be executed [13].

Definition 2.2. A planning operator $po = (name_(po),\ pre(po),\ \text{eff}^-(po),\ \text{eff}^+(po))$ is stated in a way that $name(po) = op\_name(x_1, ..., x_k)$, where *op_name* is a unique identifier and $x_1, ..., x_k$ are all the variable symbols present in the operator, $pre(po)$ is an set of predicates defining an operator's preconditions, and $\text{eff}^-(po)$ and $\text{eff}^+(po))$ are sets of predicates which characterised positive and negative effects. The instances of planning operators are called **actions**, which are created through replacing operator's variable symbols, in operator's arguments, preconditions, and effects by objects, that are specified in a planning problem. To apply an action $a = (pre(a), \text{eff}^-(a), \text{eff}^+(a))$ to a state s is possible if and only if $pre(a) \subseteq s$. The result of execution of action a, in state s, if possible, is in transforming the original state to a state $(s \backslash \text{eff}^-(a)) \cup \text{eff}^+(a)$.

Planning task solution can be characterised as an ordered sequence of actions that drive the change of the environment from the defined initial state to the desired goal state.

Definition 2.3. A plan in terms of classical planning is an ordered sequence of actions. A planning task's Σ **solution** is a **plan** Σ, which can be identified as solution if and only if a consecutive application of the domain actions applied from the initial state leads to a goal state in which all defined goal atoms of Σ are satisfied.

Further, the above definitions are demonstrated on the DWR domain examples that are presented in four separate sections such as domain, planning operator/action, and a plan examples.

Example 2.4. Lets define a DWR planning problem in which there are two locations (loc1, loc2), one robot (r1), two cranes (crane1, crane2), three piles (p1, p2, p3), and four containers (c1, c2, c3). The set of symbols is {loc1,loc2,r1,crane1,crane2,p1,p2,p3, c1,c2,c3,pallet}. The pallet is the object that is a base of a pile and it is represented by its name. Essentially, when pile is empty, lets have p2 empty, then top(pallet,p3). A figure 2.1 shows the initial state of above described domain.

It worth to point out the various form of truth values of an atom from state to state, which can be demonstrated by the atom in(c2,p2) that holds in the state shown in figure 2.1, but does not hold in a state where the cranes and robot transport the container c2 to one of the other piles. Consequently, the predicate in can be viewed as a function of the set of states and is called a fluent or flexible relation. On the other hand, there are other types of predicate symbols that does not vary from state to state. One of the example of these predicate can be the truth value of adjacent(loc1,loc2), which is a state-invariant predicate called a rigid relation [6]. It worth to note that

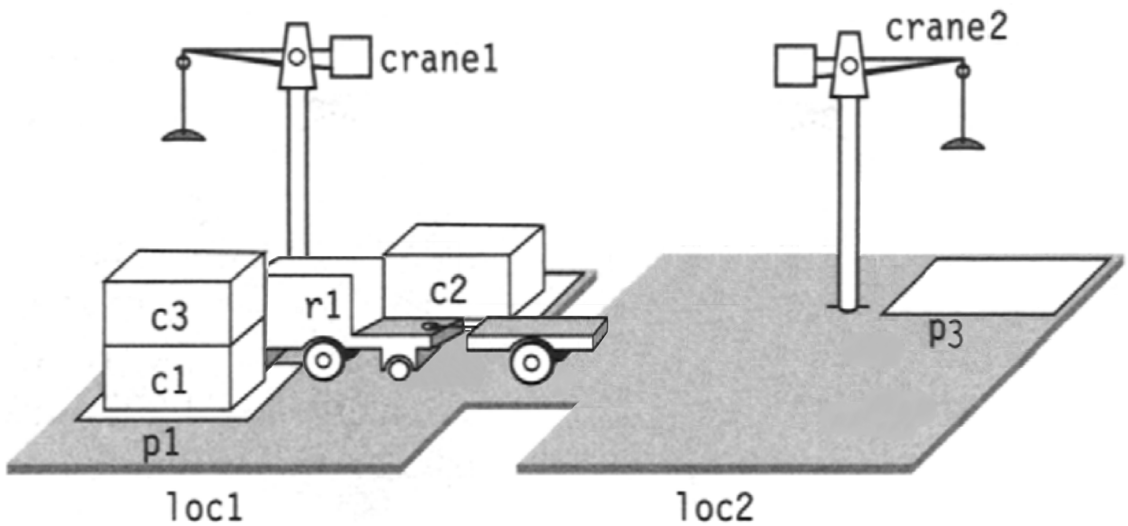

Fig. 2.2. The example of state s_1. $s_1 = \{attached(p1, loc1), attached(p2, loc1), attached(p3, loc2), in(c1, p1), in(c3, p1), top(c3, p1), on(c3, c1), on(c1, pallet), in(c2, p2), top(c2, p2), on(c2, pallet), top(pallet, p3), belong(crane1, loc1), empty(crane1), belong(crane2, loc2), empty(crane2), adjacent(loc1, loc2), adjacent(loc2, loc1), at(r1, loc1), occupied(loc1), unloaded(r1)\}$

the rigid relations cannot appear in any operator's effects as they are invariant over all the states and as such can be used only in their preconditions.

As mentioned earlier the transition between states is specified typically through set of planning operators which are later instantiated into actions. Example 2.5 presents operators of our DWR domain example [6].

Example 2.5. The DWR domain operators according to Ghallab [6].

move(r, l, m) ;; a robot r moves between locations l and m

pre: $adjacent(l, m), at(r, l), \neg occupied(m)$

eff: $at(r, m), occupied(m), \neg occupied(l), \neg at(r, l)$

load(k, l, c, r) ;; a crane k at location l loads container c onto robot r

pre: $belong(k, l), holding(k, c), at(r, l), unloaded(r)$

eff: $empty(k), \neg holding(k, c), loaded(r, c), \neg unloaded(r)$

unload(k, l, c, r) ;; a crane k takes container c from a robot r at the location l

pre: $belong(k, l), at(r, l), loaded(r, c), empty(k)$

eff: $\neg empty(k), holding(k, c), unloaded(r), \neg loaded(r, c)$

put(k, l, c, d, p) ;; a crane k puts c onto d in pile p at location l

pre: $belong(k, l), attached(p, l), holding(k, c), top(d, p)$

eff: $\neg holding(k, c), empty(k), in(c, p), top(c, p), on(c, d), \neg top(d, p)$

unstuck(k, l, c, d, p) ;; a crane k at location l unstuck c off of d in pile p

pre: $belong(k, l), attached(p, l), empty(k), top(c, p), on(c, d)$

eff: $holding(k, c), \neg empty(k), \neg in(c, p), \neg top(c, p), \neg on(c, d), top(d, p)$

The example of an instance of an action can be seen in the example 2.6. The example displays an instance of action called move that represents the robots movement from one location to another.

Example 2.6. move(r, l, m) is the first operator in the example 2.5
and move(r1,loc1,loc2) is the following operator instance:

move(r1,loc1,loc2)

;; robot r1 at location1 moves to location loc2 to by adjacent location loc1, loc2

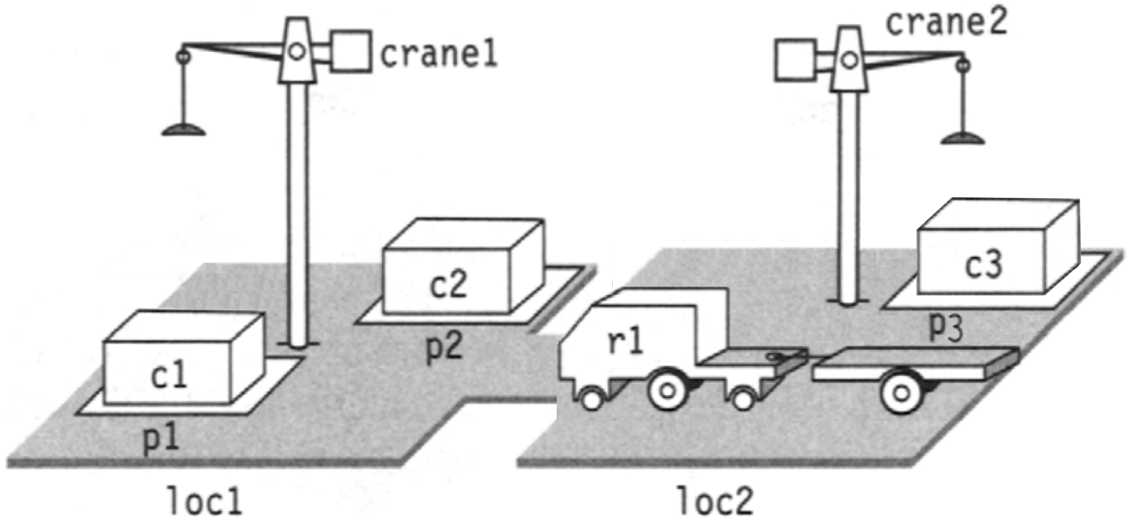

Fig. 2.3. Goal state of DWR s_6. $s_6 = \{attached(p1, loc1), attached(p2, loc1), attached(p3, loc2), in(c1, p1), in(c3, p1), top(c3, p1), on(c3, c1), on(c1, pallet), in(c2, p2), top(c2, p2), on(c2, pallet), top(pallet, p3), belong(crane1, loc1), empty(crane1), belong(crane2, loc2), empty(crane2), adjecent(loc1, loc2), adjecent(loc2, loc1), at(r1, loc2), occupied(loc2), unloaded(r1)\}$

pre: adjacent(loc1, loc2), at(r1, loc1), ¬occupied(loc2)

eff: at(r1, loc2), occupied(loc2), ¬ occupied(loc1),¬ at(r1, loc1)

Let's focus on the action from the Example 2.6. The *move* action's precondition adjacent(loc1,loc2) is a state-invariant predicate that expresses the transition of the agent between two locations, where the action's precondition $at(r1, loc1)$ represents the robot1 presence at location1 and precondition $\neg occupied(loc2)$ is a negation of *occupied*, which expresses that a robot is not present in the location2, therefore, the location is ready for the robot to be adjacent to it.

The *move* action has positive effect in changing the predicate $occupied(loc2)$ to true, changing predicate $at(r1, loc2)$, which results in negative effects $\neg occupied(loc1)$ and $\neg at(r1, loc1)$ manifesting that robot is no longer in location1 and that location1 is not occupied.

Example 2.7. move(r1,loc1,loc2) is applicable to state s_0 displayed in the figure 2.1. The result is a state $s_1 = \gamma(s_0, move(r1, loc1, loc2))$ depict in figure 2.2.

Example 2.8. Consider the following plan:

$\tau_1 = \langle take(crane1, loc1, c3, c1, p1)$

$load(crane1, loc1, c3, r1)$

$move(r1, loc2, loc1)$

$unload(crane2, loc2, c3, r1)$

$put(crane2, loc2, c3, pallet, p3)\rangle$

The plan shown in Example 2.8 is applicable to state s_2 depicted in figure 2.2 and resulting in the state s_6 that can be seen in below figure 2.3 and which satisfy the goal formula shown below:

$$g_1 = \{in(c3, p3), on(c3, pallet), top(c3, p3)\} \tag{2.1}$$

2.1.2 Numerical Planning

Classical planning abstraction does not fully represent all aspects of the real world, especially those involving numerical aspects and numerable resources. To enable addressing this kind of real-world planning problems, handling of quantitative information is crucial. Accordingly, there is a need for decision making that will execute an action on a base of certain numerical conditions, and its execution may result in consuming or renewing of some defined resource. It can be demonstrated on our example DWR domain where each transportation of a robot between location would consume a particular quantity of fuel depending on the distance it would travel and its consumption rate. Further, in this scenario, some refuel action would be required. This fact motivated the development of planning domain definition language version (PDDL) 2.1, which introduces numeric fluents and durative actions. The durative actions refer to temporal planning and as such are not subject of interest for this research. The PDDL and its version 2.1 are introduced in Chapter 2.1.3.

Numerical planning has been in past years in the spotlight of the planning community, which resulted in the development of many planners that can utilise numerical fluents. Even though the number of planers accepting numerical planning is growing planning with numerical state variables presents the planning problem with undecidability in general case. The introduction of the undecidable planning problem and the fact that not all planners support the full range of PDDL2.1 functionality often results in worse planners' performance.

To provide understanding of numerical planning, there is a need to introduce a notation of planning with numerical fluents, which is presented in Definitions 2.9 and 2.10. The numerical planning formalism defined below is based on the classical planning introduced in Chapter 2.1.1, and enhanced with numerical preconditions, numerical goal conditions, and numerical action effects. Further, the definitions follows formalism described by Helmert [14] and semantics of PDDL2.1 [10].

To be able to describe numerical planning task there is a need to firstly introduce its sets of states that are called propositional state variables V_p and numerical state variables V_n. The set of states S is defined as tuple $S = (\gamma, \tau)$ such that γ is a function of V_p which maps to true or false, and τ is a function of V_n which maps to $\mathbb{Q}$. The formal prescription can be seen in Equation 2.2.

$$S_\Sigma = \{(\gamma, \tau) \mid \gamma : V_p \rightarrow \{\top, \bot\}, \tau : V_n \rightarrow \mathbb{Q})\} \tag{2.2}$$

As a first step, it is vital to provide a definition of a planning instance.

Definition 2.9. Numerical planning instance is a tuple $\Sigma = (Dom_\Sigma, Prob_\Sigma)$, where Dom is a tuple $Dom = (V_p, V_n, Ops_\Sigma)$, where $V_p \cap V_n = \emptyset$ and V_p, V_n are finite sets of propositional and numerical state variables, respectively. Further, Ops_Σ is a pair of (pre_{po}, eff_{po}), where pre_{po} is a finite set of propositional and numerical conditions and eff_{po} is a finite set of propositional and numerical effects such that various effects affect different variables. Further detail on planning operator is provided in definition 2.10.

The planning problem $Prob_\Sigma$ is as in classical planning defined as a triple $Prob_\Sigma = (Objs_\Sigma, I_\Sigma, G_\Sigma)$, but the I_Σ and G_Σ can contain both propositional and numerical conditions.

As a next step, we provide a definition of an operator.

Definition 2.10. A planning operator $po = (name_{(po)}, pre_{(po)}\ \mathrm{eff}_{po})$, where $pre_{(po)}$ is constructed from two types of preconditions and two types of effects, these types are propositional and numerical preconditions and effects. A propositional precondition is given by a propositional variable $v \in V_p$. It is written as $v = \top$. A propositional condition is satisfied by a state (γ, τ) if and only if $\gamma_{(v)}$ is true, where $v \in V_p$. A numerical precondition is a numerical condition, which is given by numerical state variables $v_1, ..., v_n$ which are elements of V_n and a relationship operator $relop \in \ \{=, \neq, <, \leq, \geq, >\}$. It is written as a function of $(v_1, ..., v_n)$ relop 0, and satisfied in a state $s = (\gamma, \tau)$ if and only if function of $(\tau(v_1), .., \tau(v_n))$ relop 0.

The first type of effect is called propositional effect such that $v \leftarrow t$, where $v \in V_p$ and $t \in \{\top, \bot\}$. The second type of effect is called numerical effect such that $v_1 \leftarrow f(v_1, ..., v_n)$, where $v_1, ..., v_n \in V_n$ and $f(v_1, ..., v_n)$ is a functional symbol.

Actions are grounded instances of planning operators and a solution of a planning problem is defined analogously to classical planning which is shown in Definition 2.3.

An example of numerical planning will be demonstrated on previously used DWR domain. The example of numerical planning will be shown on two states, which are provided in Figures 2.1 and 2.2, and two actions that are shown in Example 2.11. The difference between our examples of classical and numerical DWR domain is that the numerical planning domain has additional planning operators such as "refuel" and robot has fuel capacity and consumption indicating how far the robot can travel without refuelling. Figures 2.1 and 2.2 present two states where robot r_1 is at location loc2 and an action move is used to transport the robot r_1 to loc1.

Example 2.11. The DWR domain operators according to Ghallab [6].

move(r, l, m) ;; a robot r moves between locations l and m pre: $fuel(r) \geq consumption(r,l,m)$, $adjacent(l,m), at(r,l), \neg occupied(m)$

eff: $fuel(r) \leftarrow fuel(r) - consumption(r,l,m)$, $at(r,m), occupied(m)$, $\neg occupied(l), \neg at(r,l)$

refuel(r, l) ;; a robot r is refuelled at location l

pre: $at(r,l)$

eff: $fuel(r) \leftarrow fulltank(r)$

From Example 2.11 it can be seen the additional preconditions and effects for the action move, which are the fluents $fuel$ and *consumption*. The fluent *consumption* provides the robots rate of fuel expenditure when moving between locations. The effect of *move* shows that the $fuel$ is a function of robot's fuel subtracted by its consumption. Finally, there was a need for an action $refuel$ as without it the robot would not be able to move as it would consume all the full within few steps.

2.1.3 PDDL

To be able to represent and share planning domains, McDermott et al. [15] introduced a language called Planning Domain Definition Language in 1998, which is typically addressed with its acronym PDDL. The introduction of this standardised language has resulted in considerable progress in planning research with deterministic planning models, especially since the first International Planning Competition in 1998 [16]. PDDL is an action-centered language, which has been inspired by the well-known formalism STRIPS [10] and its syntax resemble a programming language Lisp. The purpose of introducing PDDL is a standardisation of the syntax, which has been developed in order to express semantics of actions, their preconditions and effects.

This action-based language divides the profile of parameterised actions, that define a domain ability to perform operations on the domain objects, definition of the specific objects, initial states and goal states that characterise a problem instance. In other words, the planning task is separated into two components, which are planning domain itself and a planning problem description. To be able to create a planning problem one needs to connect the defined domain with the problem description [16]. Further, it is possible to define multiple problem descriptions and apply them to the same domain.

Action parameters are dependent on the application of variables that are representing terms of the problem instance. To put it differently, the action parameters are attached to objects that are defined in the specific problem instance, when an action is picked for execution. In PDDL, action's preconditions and effects are described as logical prepositions that are derived from problem instance objects, predicates, and logical connectives. Also, PDDL furnishes the ability to express a type structure of domain objects, parameters of actions and constraining the types of arguments to predicates and actions that have negative preconditions and conditional effects [10].

Even though the heart of the PDDL is STRIPS formalism, the language extends beyond that. For example, in this language, it is enabled to have negative preconditions and conditional effects in action description and ability to use of quantification in expressing preconditions and post-conditions.

In addition, PDDL enables expressing of an object type structure in a domain, defining the parameters which appear in actions and constraining argument types to predicates. During the planning process execution and especially in the grounding stage, the parametrised actions are then replaced by a set of grounded actions where formal parameters are replaced for actual values [17]. Another significant PDDL's functionality is the ability to represent functions whose value can change according to different situations, which are numerical variables known as fluents. Further, these functions enable expressing numeric quantities which can be assigned or updated. Numeric fluents are useful for expressing realistic domains which deal with non-binary resources. Essentially, this points towards numerical planning, which is explored in chapter 2.1.2 and PDDL2.1, which is discussed below.

There are several versions of PDDL that with each new version introduce new planning functionality [18]. These PDDL versions are listed bellow:

- PDDL 1.2 - This was the first version of PDDL introduced and used at the first two IPCs in 1998 and 2000.

- PDDL 2.1 - In this version were introduced numeric fluents, plan-metrics, and durative/continuous actions. The new functionality of this version enabled representation for many real world scenarios. Further, it was the official language for the IPC in 2002.

- PDDL 2.2 - It was PDDL version used for IPC's deterministic track in 2004. The new functionality introduced in 2.2 were derived predicates, which enabled modelling of dependency of given facts from other facts, and timed initial literals.

- PDDL 3.0 - This language was introduced in the 5th IPC's deterministic track in 2006. The main advancement of this version was the introduction of state-trajectory constraints and preferences or soft goals, which enabled preference based planning. Version 3.0 reflected in its expressiveness the recent important developments in the planning.

- PDDL 3.1 - This was the language version introduced in the 6th edition of the IPC and then exploited in subsequent 2014 and 2018 editions. The main advancements were the introduction of object-fluents and some syntactical improvements, which semantically had a significant influence in expressiveness.

As our research is concern with numerical planning our interest lays in PDDL version 2.1, which is further detailed bellow.

The **PDDL2.1** is the product of the IPC's completion, which took place in 2002, objective to close the gap between planning research and its application. This meant to define a language in which is possible to encode a certain classes of temporal and resource-intensive planning domains. Further, it has been developed with backward compatibility in mind to enable usage of planners that has been built on previous version of PDDL and to preserve a number of design principles that are important to be preserved [10]. In other words, PDDL2.1 extends PDDL in principled manner to attain the additional expressive power. This is done by following maxim ”physic, not advice” [15]. To put it differently, it means that the language is build to focus on physical properties of the world rather than to provide advice to planner how to search the associated solution spaces [10]. On the other hand, Fox and Long [10] state that any model of physical system is made by certain degree of simplification and abstract behaviour and as such no model can be claimed purely physics and free of decisions which could effect the use of model.

Fox and Long [10] divided the extensions of the language features into five levels according its expressing power, which are:

- **Level 1** - fragment of STRIPS
- **Level 2** - numeric extensions
- **Level 3** - discretised durative actions
- **Level 4** - continuous durative actions
- **Level 5** - bundle of all extensions

In this thesis we are mainly concerned with the level 2, which is discussed below.

The ability to use numbers in domains creates platform for measuring consumption of critical resources and other parameters, which can be observed in the example 2.11 in the Chapter 2.1.2. This ability is vital for many real world planning problems in which it is important to minimise the consumption of the resources and as the plan quality can be dependent on number of interacting domain-dependent factors [10].

The expression of numeric fluents and its syntax is according Fox and Long [10] based on the version defined by McDermott [15], with minor differences explained below.

The numeric expressions are composed of primitive numeric expressions which use arithmetic operators. Further, they are linked with tuples of domain objects by domain functions. The syntax for expressing numeric assignments and updates can be seen in the example 2.12. From the example can be seen that all arithmetic operators, including comparison predicates, are done by using a prefix syntax. The prefix syntax was according Fox and Long [10] done to simplify parsing. Further, numeric conditions are always composed of pairs of numeric expressions, where one is compared to other. Additionally, assignment operations may be used in effects to update primitive numeric expressions values, which include direct and relative assignments. Effects can make use of a selection of assignment operations in order to update the values of primitive numeric expressions. Numbers do not have specific roles and as such can for example represent counters, quantities of resources, quantities of resources, or indices [10].

Example 2.12. A example of the move action from the DWR domain in PDDL 2.1.

```
(:action move
:parameters (?r - robot ?loc1 - location ?loc2 - location )
:precondition (and (>= (fuel ?r) (consumption ?r ?loc1 ?loc2))
              (adjacent ?loc1 ?loc2) (at ?r ?loc1)
              (not (occupied ?loc2)))
:effect (and (decrease (fuel ?r) (consumption ?r ?loc1 ?loc2))
        (at ?r ?loc2) (occupied ?loc2) (not (occupied ?loc1))
        (not (at ?r ?loc1)))
)
```

Numeric expressions cannot be encoded as arguments to predicates or values of action parameters. Fox and Long [10] stated that there is a finite number of objects in the world and also numbers do not exist as unique and independent objects in the world. Further, numbers are manipulated exclusively through their the initial state's object relationships. It is important to highlight that PDDL2.1 functions are restricted to be type of $Object_n \rightarrow \mathbb{R}$, for the finite collection of objects in a planning instance, Object and finite function arity n [10].

In this chapter we introduced classical planning, numerical planning and PDDL language serving for the description of the planning domains. The next chapter is introducing sport science concepts such as physical abilities of athletes, introduction into sport performance, testing of athletes, introduction into kickboxing and last but not least introduction into sport planning.

2.2 Sport Science and Training Theory

As this study aims to introduce the theory of sports science into automated planning, there is a need to define what sports science is and what concepts in this area are essential for this study.

The sports science is a discipline which studies physiology reactions to exercise, training, different environments and any other stimuli aimed for athletes performance enhancement which leads to the edge of their physical boundaries. It is a collection of sub-disciplines, such as physiology, biomechanics, nutrition, strength and conditioning, psychology and performance analysis.

According to Bishop [19] sports science focuses on understanding and enrichment of sports performance. Sports science can be considered as a study that is using the scientific process to steer the practices of sports training with the primal goal to improve sports performance [19].

Sports science (SS) can also be identified as a study that aims to maximise competitive athletic performance. With this goal in mind, SS explore the interactions of physiology, biochemistry, biomechanics, nutrition, and endocrinology fields of study, with various training paradigms and training programs to accomplish given goals [20]. Simultaneously, the SS also concerns the maintenance of athletes' performance during periods of high-intensity training. Further, one of the important subjects of SS is examining fatigue, over-training syndrome, which provides an insight into recovery from exercise and techniques to help overcome it. Understanding of athletes' fatigue and over-training syndrome are not only important for athletes' performance enhancement but also injury prevention [21]. Last but not least, the SS concerns sports performance prediction which can identify talented individuals that is crucial for the selection of athletes.

In other words, the SS aims to use the best available evidence of training practices provided at the right time, the right environment and for the right individual to enhance their performance. Athletes' performance improvement is reached by using and implementing the findings of well-designed research into training programs [22].

Sports science research significance is highlighted by the fact that sports are more and more performance-focused and success in a nowadays international competitive world cannot be accomplished without employing scientific approaches [23]. On the other hand, there is a need to bear in mind that, like any science, it is a long process to implement results of research into a day to day practice [20].

Nonetheless, nowadays, there is a vast amount of resources, which forms these findings into the literature that is aimed for coaches education. This literature provides a wide range of sports training knowledge, which is explored to collect the crucial pieces and use them as inputs for the development of the proposed sports domain.

The main concepts of sports science and training theory which are explored in this study are physical abilities and understanding of physiological mechanisms that enable the human body to execute the physical activity, sports training planning, sports performance and athletes testing that serves to measure the athletes' performance outcomes.

Understanding these constructs is crucial for being able to define and grasp the proposed domain model, which is described in the next chapter.

It is essential to reckon that each sport requires a unique approach to sports training. To be able to implement the sports domain there is a need to start with one specific sport, which in our case is kickboxing. This sport was chosen primarily because the author of this study has more than ten years of experience and has level 2 coaching, which provides him insight into this area.

Nonetheless, this study does not aim to focus on one individual sport purely but to provide general sports model for physical preparation. Nevertheless, kickboxing is serving as a stepping stone that will give specific physical athletes conditioning and in a later stage will enable us to provide a model that can be easily manipulated into different sports fields.

2.2.1 Physical and Movement abilities

Physical abilities and their measurement is considered as an integrated scale of all functions and structures such as energy metabolism (cardiorespiratory, endorcine-metabolic, hematocirculatory), sceletomuscular, and psychoneurological, involved in exercise execution [24]. Dovalil and Peric [25] views physical abilities as relatively independent complex of human internal predisposition for physical activity and their manifestation.

According to Mekota and Blahus [26] physical abilities are a collection of integrated internal predispositions of organism, and for some of them can be found biological basis. In other words, physical ability is a well-designed concept, which provides fixed and generalised model, used for forecast of and individual performance and outcomes in particular activity [25]. Further, physical abilities are the result of complex connections and synergies of various systems, which take a place on the level of biochemical processes, physiological functions, and mental processes. These can directly relate to physiological condition of general stamina that is mainly govern by cardio-circulatory system functions. With this in mind anatomical differences play a major role in physical activity outcomes therefore sport performance [27].

Dovalil and Peric [25] defines physical abilities into two categories:

1. Fitness abilities

2. Coordination abilities

Fitness or fitness-energy abilities include stamina, strength, and partly speed abilities, energy factors and processes mainly define these abilities. The energy factors are defined by aerobic and anaerobic system.

Coordination or coordination-psychomotor abilities are practised by functions and processes of movement coordination that serves for managing and controlling execution of physical activity. Into this category belongs balance, orientation, rhythm and reaction. Further, there are other abilities that are between those two which are called fitness-coordination abilities [25].

These physical abilities that are used within our developed sport domain are described in following subsections.

Energy systems

All physical abilities are influenced into some extend by metabolic processes. The exercise execution is dependant on energy production and usage. For that reason, this section investigates energy systems and their functions as their main purposes are production and use of body energy. Further, understanding of energy transfer enables us to develop effective and efficient training programs [28].

When analysing exercise execution it is possible to observe interconnection of internal predispositions and integration of biochemical processes, physical functions and psychic manifestations [27].

According to Votik and Zalabak [29] physical abilities are dependent on quality of physiological processes happening in the human body through which we obtaining energy necessary for movement execution. The energy systems and their activation is depending on a type of activity performed. According to the type of exercise energy is released:

1. Without oxygen access
    - immediately, this occurs when exercise is executed with maximal intensity with time range of 15-20 seconds (conditioning of individual speed and explosive strength).
    - short-term, the exercises are performed almost with maximum intensity lasting maximally 2 minutes (development of speed endurance).
2. With oxygen access
    - long-term, this occurs when physical activity is performed in low to medium intensity and last more than 2 minutes (conditioning of endurance/stamina).

The energy system governing energy supply without oxygen is called anaerobic system. Anaerobic system can be further the anaerobic system is divided into to sub systems, which are ATP-CP and Lactic Acid system [30]. On the other hand, the energy system supplying energy with access to oxygen is called aerobic system. Each system is activated during different type of exercise and in many cases they are activated at the same time. The activation of these systems depends on exercise type, intensity and duration. A general model of system activation can be seen in graph bellow.

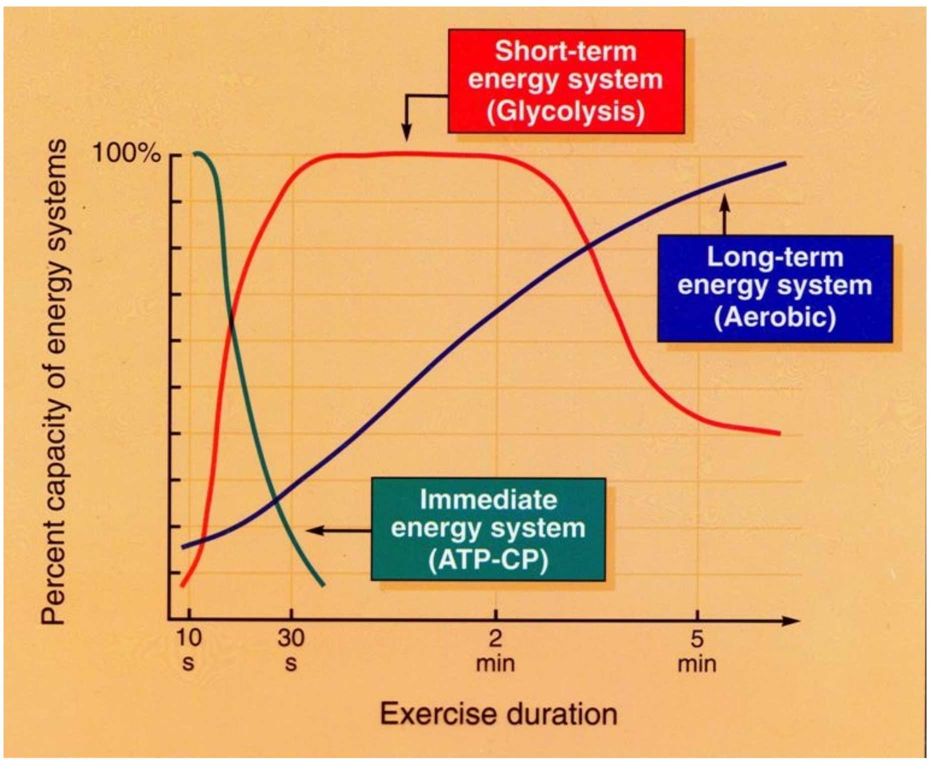

Fig. 2.4. Percentage activation of energy systems according to duration [31]

The following subsection anaerobic system in further detail, which is followed by aerobic system.

Anaerobic system

Muscles are adapted to create energy by use of both glucose, which is stored as glycogen, and fatty acids, which are stored as triglycerides. Both of these energy sources are taken from the circulating blood and stores within the muscle [30]. The triglyceride (fatty acids) energy source is used in a higher percentage in long duration exercises performed with low intensity. On the other hand, short high-intensity exercises rely on the usage of muscle glycogen therefore anaerobic system. Anaerobic system is composed of two subsequent systems, which are ATP-CP and lactic acid systems.

ATP-CP system is based on a adenosine triphosphate (ATP), which is generated through multiple reactions of a body and allows a transfer of the energy. It is a high-energy intermediate molecule that stores large amount of energy within its chemical bonds. This molecule enables us with the initial movement of any activity and without appropriate supply of it a muscular growth would not be possible. What is more without ATP the body movement would not be possible at all. Further, the ATP is the primary source of energy for short-term high-intensity exercises such as sprinting [30]. This energy source usually can last approximately up to 90 seconds and after you can feel burning feeling in your longs as you begin gasping for air. The name of anaerobic indicates that the muscle activity is done "without oxygen". This means that the body cannot supply blood with nutrition and oxygen in sufficient rate which is demanded by working muscle. After initial usage of ATP it is broekn down into adenosine diphosphate (ADP) and in order to create additional amount of ATP a creatine phosphate (CP) is required. The ADP together with CP is transformed into ATP. Without CP the ATP storage would last only about 30 seconds. Therefore, ATP-CP system supply the immediate anaerobic power [30].

Lactic acid system is a transitional system that is triggered after a physical activity that exceed 30 seconds (when performed at the highest intensity). This system continues to provide a muscle ATP by using the muscle sugar. This process is called glycolysis as the muscle sugar is in form of glycogen. This system is also called glycolytic system or anaerobic glycolytic system as it is a process of braking down glucose (sugar). The process is a series of ten enzyme-controlled reactions, which uses carbohydrates to generate ATP and pyruvate (lactate) as end products. During this breakdown the glucose has to enter cell membrane which starts the process. When the cell enters the sugar will start to transform and the ten glycolysis reaction occurs very rapidly, which generates two ATP and two pyruvate molecules (lactate) [32]. Glycolysis is a human body preferred energy system for any sort of movement or physical activity [28]. As mentioned above, glycolysis forms a waste product which is a lactate. If the body is unable to clear the lactate it will experience a muscular fatigue. The lactate is cleared away when the exercise is lowered to moderate intensity as an aerobic system activates and supplies energy for long-term work.

There is a limited amount of ATP stored in muscles and for that reason three primary energy systems exist and generates ATP, which constantly regenerates it for physical activity. With this in mind, all of the energy systems are stimulated at the same time. Nonetheless, the contribution and dominance of each system is dependent on the intensity and duration of a particular muscular activity [33].

Aerobic system

The aerobic system serves as a supply of energy for steady physical activities that are executed for a longer time. The aerobic system function can be described as a cooperation of cardiovascular and respiratory system carrying oxygen to performing muscles producing energy in the presence of oxygen [33]. To put it differently, aerobic means "with air" and as such the aerobic activity is relying on heart, lungs, and blood vessels to transport oxygen to the muscles [34].

The amount of the system activation depends on the type of exercise. The aerobic system is activated with long duration exercises executed with low intensity. For example the system is under maximal load when performing long distance running or swimming. When the oxygen system is under load the primary energy source is usage of triglyceride (fatty acids) [30].

Further, if the aerobic system is highly trained, muscles under aerobic load are able to produce ATP and provide increased efficiency of restoring anaerobic power during longer lasting physical activity [30]. When the aerobic system is well trained, the body works efficiently and provides the means to increase intensity in the important stages of sport competition.

The aerobic system is closely connected with athletes endurance, which is defined as an ability to continuously perform particular activity on a certain level without decreasing effectiveness.

Endurance

Endurance abilities are mainly related to the activation of the aerobic energy system. Nonetheless, anaerobic lactate energy system plays an important role during short and long-term endurance exercises [34].

When body is under physical load it generates lactate, which results in low to moderate acidification. This has a negative consequence on the central nervous system (CNS). Without clearing the lactate from the organism further performance of physical activity is not possible [25]. The primary assumption of high level of endurance lies in a performance of cardiovascular and respiratory systems. The main limiting factor of endurance is the lack of sufficient supplies of nutrients and oxygen [31].

Training focused on endurance highly improves the function of a circulatory and respiratory system and therefore increases their scope and effective usage [27]. Need to highlight that endurance is interconnected with a technique of an activity that is being executed as the precision of movement decreasing energy demands. There are several types of endurance which are determined by duration of exercise or percentage of energy supplied by aerobic and anaerobic systems [35]. These endurance types are as follows:

1. **Long-term endurance** - can be defined as an ability to perform exercise with a specific intensity longer than ten minutes. The main supply of energy supplied aerobically with access of oxygen using glycogen and in later stage fatty acid. The fatigue comes from depletion of all energy sources.

2. **Medium-term endurance** - is performed with the maximum level of aerobic system activation and maximum consumption of oxygen. Typically the physical activity with a time duration of 8 - 10 minutes. The primary limiting factor is an athlete capabilities of cardiovascular and respiratory systems. This type of activity is supported by lactic acid system. The main energy source is glycogen, and its exhaustion results in fatigue.

3. **Short-term endurance** - is demonstrated by activities lasting 2 - 3 minutes performed with high intensity. The main source of energy is the glycolysis system, which means that the release of energy is occurring without access of oxygen. The fatigue is coming by accelerated accumulation of lactate.

4. **Speed endurance** - is the ability to perform exercises with the highest intensity for the longest time. This is typically lasting maximally up to 20 to 30 seconds. The energy supply is based on ATP-CP system.

As mention above endurance can be also categorised by energetic coverage of energy systems. These two categories are aerobic and anaerobic endurance.

According to Peric and Dovadil [25], endurance capabilities are fundamental precondition for high level sport performance. The appropriate endurance level will enable athlete to endure high level of physical load during training program. Further, good level of body endurance positively effects recovery after exercise and by those means prepares body for next performance.

A sport performance is highly dependent on results of complex endurance abilities but sport performance is also reflection of other abilities such as speed strength, agility, coordination and technique. Nonetheless, endurance is a backbone for development of other abilities [25].

Strength abilities

A strength can be defined as an ability that enables to perform physical activity with great deal of force and is directly connected with muscle function, which can be defined as muscle strength. Nonetheless, strength abilities need to be characterised differently as forces in individual muscles are not the result strength. This comes from the fact that muscles during motion working contradictory against each other in antagonists and agonists through joints in vast variation of freedom degrees [27].

Strength can be understand as an individual ability to overcome resistance or act against the resistance through muscles tension. This resistance can be in form of gravity and its resulting weight of the body, weight of load or persistence of other objects.

Hofman, Lames and Latzelter [36] are determining strength abilities as a central component of sport performance and subject of sport training. Additionally, Havel and Hnizdil [37] characterise strength abilities as an individual basic and decisive capabilities without which other abilities cannot manifest during physical activity.

A complex of strength abilities is a collection of internal predisposition and the effort of emitting a force in terms of physics by muscles. Optimum strength enables athletes to execute physical tasks efficiently and effectively perform during training programs and competitions [38].

As strength abilities are one of the main components of physical abilities and major part of sport performance. Therefore, their development is one of the primary subjects of sport training [36].

Strength abilities can be divided according to muscle contractions, which is defined by length and tension of the muscle, which are:

- Isometric (static) during an isometric physical activity the muscle or group of muscles contractions do not visibly change their length although the tension of the muscle is elevating. As an example can serve pushing against a concrete wall.

- Isotonic (dynamic) during the dynamic physical ability the tension in the muscle or muscle group stays more or less same but the muscle length changes. Into this category belongs most of the exercises in, which any movement is involved.

The basic categorisation of strength abilities is divided according to a magnitude of resistance and speed of a motion, which are direct results of activation of specific muscles fibres, duration of motion and activation of energetic systems. According to Peric and Dovalil [25], these categories are maximal strength, speed strength, reaction and explosive strength, and endurance strength.

- Maximum (absolute) strength: is an ability to endues muscle contraction of the highest possible strength during static or dynamic physical activity. Typically it is performed through a single repetition of particular exercise. During examination of maximal strength is considered the maximal resistance or maximal contraction of the muscle. Further, the maximal strength is a base for other types of strength abilities.

- Speed strength: is ability connected with overcoming resistance with high to maximal speed, which can be realised during dynamic muscle activity. Speed strength has elements of speed and strength. In other words, speed strength is manifestation of central nervous system reaching the highest muscle impulse in time interval of physical activity. Speed strength can be divided into start and explosive strength. Start strength is determined as performance of movement with highest speed in the shortest time where explosive strength is described as an ability to create the maximal acceleration in the shortest time possible in the last phase of movement.

- Reactive strength: Lehnert et al. [38] defines reactive strength as an ability to use eccentric muscle contraction to reinforce the concentric contraction. To put it differently, a reactive strength is ability to generate optimal combination of eccentric lengthening of muscle and following concentric shortening of muscle.

The magnitude of concentric strength is dependent on maximal strength, speed strength and elasticity.

- Endurance strength: is the ability to endure continuous physical ability with resistance bellow maximum. The maximal resistance should be bellow 30% of maximal strength [36]. Endurance strength can be characterised as an ability of organism to overcome fatigue [27]. To differentiate endurance strength from classical endurance it is need to consider its dependency on maximal strength when overcoming resistance and the energetic coverage. Strength endurance is divided into static and dynamic endurance strength. The dynamic type is related to performing exercise repetitively in time interval without drop down of performance. The static type is related to continuous exercises in which an athlete needs to persist for longer time period.

Categorisation of strength abilities varies in literature but most of the authors agrees upon superiority of maximal strength in hierarchy of strength abilities [25, 26, 30]. Individual physical abilities do not exist isolated but they are always part of motion reaction. Muscle strength is applied in other movement functions and abilities. A training programs has to be always in equity with absolute, speed and endurance strength in order to be able to not only maintain but also progress further in sport performance [25].

Speed Abilities

Speed is the ability to perform physical activity in time interval bellow 15 seconds. The activity is executed with the highest intensity and none to low resistance, which is 20-25% of maximum resistance. To put it differently, a motion speed can be defined as an ability to perform physical task in the shortest interval with high to maximal speed [38]. In other words, to consider an activity as a manifestation of speed ability it has to be performed with high to maximum intensity. Further, the speed activities are energetically covered by ATP-CP system.

While performing speed related activities it is important that fatigue is not present as it is decreasing motion intensity. This emphasises the importance of the development of recovery function of CP that enables to execute motions repeatedly and without loss of quality [25].

Motion speed is affected by a complex of numerous factors. The crucial factors are high instability phenomena of irritation and depression of a central nervous system and its equivalent contraction and relaxation speed of muscles and speed of nerve impulses conduction. Also, with higher movement speed also rises demands for coordination of antagonistic muscle groups. Morphologically speaking speed abilities are dependent on the proportion of fast muscle fibers [35].

Further, speed abilities play important role in sport performance. A speed is considered as a hybrid ability as it relies on athlete's fitness level and coordination predispositions [27].

According to Sands et. al. [28] speed can be categorised into active, frequency, and complex speed.

- **Active Speed** - is an ability to move rapidly with great precision in time span lesser than 6 seconds. Typically involves acyclic movements.
- **Frequency Speed** - is ability to incorporate speed in cyclic movement. As examples of cyclic activities can serve running, rowing, or swimming.
- **Complex Speed** - the ability to connect re-activity and perception which is promoted into a goal-directed movement. This type of speed mainly includes noncyclic activities.

Another view on speed categorisation is provided by Lenhart [38]. He classify speed abilities into reaction, acyclic, and cyclic speed.

- **Reaction Speed** - is the capability to carry out motion on particular impulse in the shortest time. Reaction speed is connected with initiation of motion. The motion initiation duration is the result of reaction speed.

- **Cyclic Speed** - can be determined as a repetitive and continuous motion activity performed in high frequency [38]. It is typically the fastest movement in space. For example running from point A to point B.

- **Acyclic Speed** - speed is an ability to produce the maximal speed of an individual motion with low to no resistance. The manifestation of acyclic speed can be seen at the beginning of a movement which is required for high level of speed-strength. The example of individual motion can be a boxer punch.

In order to achieve maximal speed potential it is important to bare in mind that speed abilities relaying on other abilities such as strength, endurance, agility and coordination [25].

Coordination abilities and Agility

Coordination is an ability that enables own body to control and regulate movements [35]. According to Deuster et al. [30] coordination is an ability to perform physical activity accurately with use of senses such as sight. Coordination abilities are intimately connected with the function of the central nervous system. Coordination is composed of a complex of relatively individual abilities which have a different proportion of participation on specific physical activity [39]. The compound of coordination abilities includes balance, spatial orientation, rhythm, differentiation, reaction, dynamic equilibrium, combining movement operations, and adaptation of movement behaviour. Each sport demands a particular level of coordination skills and their development. The perfection of physical ability management and execution is directly dependent on coordination skills which are interconnected with central nervous system activity and individual senses (acoustic, vestibular, kinaesthetic and optical).

In other words, the coordination skills that are governed by the central nervous system and the senses involved in the physical activity enables the highest efficiency of kinematic and dynamic structures of the activity movement. As such higher coordination skills positively influence motor learning, which leads to faster adopting of new techniques and exercises and further development of physical activities [34].

In practice, there is in many cases confusion in separating coordination and agility abilities. The coordination abilities serve for internal control of movement that can be described as the interaction of a central nervous system and a neuromuscular apparatus. Where agility is an ability which is an external manifestation of coordination and can be defined as an ability to realise complex coordination demanding movements [25]. Further, it is a capability to learn those movements fast and adapt them to changing condition [26].

There are two categories of coordination abilities which are general coordination and special coordination. General coordination is the ability to effectively execute motion independently on sports specialisation. Athletes who possess better general coordination to implement specific coordination requirements of a sports specialisation faster. To positively impact general coordination it is vital to practice new moves from different sports and games. In other words, the process of learning new moves positively influences the abilities of the musculoskeletal system and its functioning with the central nervous system.

Special coordination is linked to individual sports branches, and it is an ability to execute a multitude of movements not only quickly but also with precision and error-free. This type of coordination 0is tightly connected to an athlete's skills and abilities applied during training units and competitions. Athletes are forming and improving their special coordination through their whole careers by regular training of physical 0abilities and technical elements [25].

It is important to bear in mind that each individual possesses a different level of coordination. From the training program point of view, it is necessary to highlight that level of coordination abilities highly influences in some cases even conditioning the ability to successfully learn, execute, or develop a technique of physical activity, or a specific sport.

This needs to be considered during training program creation as athletes with lower coordination skill could not be able to execute planned tasks. Nonetheless, coordination skills can be improved [39].

Flexibility

Flexibility is described as an ability to reach an optimal range of motion which is demanded while performing physical activity. The motion range is derived from amplitude in joints and is caused by internal and external forces [38]. Many sports require high flexibility in particular joints as without it realisation, acquisition, and then precise execution of sports techniques would not be possible [26].

Further, a high level of flexibility reduces the risk of muscle injury, especially when practising new techniques and some unexpected or uncoordinated move occurs. For that reason, it is important to include into training units stretching, compensation stretching and balance oriented exercises that develop flexibility and help to avoid unfavourable effects of a one-sided load. Consequently, there needs to be put emphasise on flexibility development even if the particular sport is not flexibility oriented [25].

It is important to mention that body flexibility is influenced by heat. In other words, higher temperatures enable muscles and joints to reach a greater amplitude of motion. On the contrary, lower temperatures decrease the motion range. From this fact follows one of the basic needs before any physical activity that is warming up and stretching, which has a similar effect as environment temperature. Nonetheless, the outside temperature needs to be considered during sports performance as it dramatically influences flexibility.

According to Dovalil and Peric [35], differences between flexibility performance was recognised with different time of the day. For example, directly after waking up flexibility is at the minimum level.

2.2.2 Kickboxing

Kickboxing is a group of martial arts which are derived primarily from Japanese, South Asian, and Western full-contact combat sports, which not only enable to use upper limbs to hit the opponent but also enable to use lower limbs techniques [40]. Further, the most effective kickboxing techniques have been passed from western boxing, Muay Thay, and karate. These distinct martial art techniques have been coherently merged into one of the most popular martial arts sports in the world.

Kickboxing combats are carried out in a standing position called the guard. This means that when one of the athletes falls on the floor referee interrupts the fight and returns them to the guard with exception of knock down.

To win a kickboxing game (bout) athlete/fighter needs to collect more points than his/her opponent till the end of the match. Points are assigned by three ring judges, to the judge's card, for every legal strike by punch or kick. At the end of the match, the results from individual judges are collected, and a result is presented. There are several point systems available. The most currently used system is the ten point system where each judge assigns 10 points to a winner of the round and 9 to the loser. If one of the fighters is knocked down with a count, the judge appoints only 8 points [41]. Nowadays at international events, the scores are recorded electronically instead of using traditional judge's cards. A point is assigned only if at least two judges register a legal strike at the same time. There are additional ways of winning the fight, such as knockdown (KO), technical knockdown (TKO), and corner retirement (RTD) [42]. KO occurs when one of the fighters get hit and is not able to continue with the match. The referee declares TKO result in the following situations:

- a fighter is unable to continue because of serious injuries, such as cuts or bruises.
- boxer is unable to defend, which can occur when an opponent is immensely and undoubtedly better. In such circumstances, the referee can deem the fighter.
- last but not least, the fight can be ended by RTD which can be done between by the fighter or by the fighter's seconds deciding that he/she should not continue.

A full match length if not prematurely ended depends on kickboxing discipline and if the fight is in amateurs or professionals. Standard amateur bouts are usually three rounds lasting 2-3 minutes with a 1-minute break between rounds where a professional fight can have three to twelve rounds.

Further, kickboxing competitions are governed by rules that vary according to a particular discipline and the organisation in which the match takes place. There are many associations nonetheless the most prestigious are WAKO, WKA, ISKA and IKF. Each organisation has its own rules; however, there are no major differences. In contrast, kickboxing disciplines can have moderate to many differences. The main disciplines in kickboxing are as follows:

Point fight - it is non-full contact discipline. The fight itself is usually realised on tatami which is usually squared area proportionally comparable with ring size which does not have ropes. The point match begins from initial positions in the centre of the ring and after each point fighters are returned to these positions by the referee. It is possible to make a point without landing a thrown punch. Nonetheless, it has to be clear which fighter would land the punch or kick first. In this discipline, the contact is from none to moderate. What is more, strikes which are landed with full force are penalised.

Light contact - same as point fighting the match is realised on a tatami. The fight itself has the same rules as full contact discipline with the difference of an amount of contact involved. To put it differently, light contact does not allow to execute techniques with full force, therefore, techniques intentionally completed with full force are penalised. However, to receive a point the technique has to land on an opponent's body.

Full contact - as the name of the discipline reveals the executed techniques are executed with full strength and effort. The combat takes a place in the ring which is usually platform with four columns and ropes between them creating a squared fighting area. The rules are the same as in boxing. Points are gained only if clean technique full impact in clearly with moderate to maximal momentum. Kicks and punches can land only at the waist level and above with an exception of kick called foot sweep. If the kick is landed anywhere else it is counted as a foul.

Low-kick - is a discipline that has the same rules as full contact except for kicks that can land on fighter's legs. This discipline is named according to this exception kicks that are called low kicks. Even though it would seem that this discipline is redundant to full contact it would be a mistake as this kick itself completely changes strategy. This flows from the fact that the low kicks when effectively executed can immobilise opponent in such a way that he/she cannot continue and combat is ended.

K-1 - again this discipline has the same rules as low-kick with some additional techniques allowed. These techniques are clinch and knee kicks. The clinch is a holding technique in which is a fighter allowed to grab opponent head. This is allowed only for a few seconds and has to be used for attacks by a knee. If fighters get into clinch for more than few seconds referee stops the fight and move them into the centre of the ring to continue the combat.

In addition, Some of the organisation have some special disciplines such as light low kick discipline, which is a combination of low-kick and light contact.

All of the disciplines include some identical protective gear, such as boxing gloves, and mouthguard. There are some differences between the disciplines' required a kit. For example, in point fighting, the athletes use a different type of gloves. Further, amateur matches require a helmet and shinguards.

When athletes are training for a fight, they often use an additional protective kit to prevent injuries in the training period. For example, boxing gloves with extra padding are used. These are usually used during simulated fights called sparing. Sparing can have various form in terms of intensity. Springs can be performed with low intensity to try out new techniques or with high intensity to prepare for a competition like combat which is demanding for a physical and mental condition. The competition is a climax of all athletes efforts. Kickboxing training programs are challenging and require a large amount of effort, focus, and physical and psychical endurance. As such, training for competition demands maximal commitment. Further, to appropriately prepare for competitions the training programs have to be well designed. It is essential that a coach posses appropriate knowledge and experiences, which are transfer into such training programs. It is also crucial to understand the sports performance and planning, which will be discussed in following sections.

2.2.3 Sport performance

Sports performance can be defined as a demonstration of particular abilities of an individual or a team in a sports event. The subject of athletic performance always has been a challenging area of sports science research. This flows from the fact that it is an enormously complex multifactorial phenomenon, which is defined by a diverse number of factors. These factors are intrinsic such as genetics, coordination, physiological and psychological state, and extrinsic such as development opportunities, training programs, nutrition, and overall health. The complexity is not form only by these factors but also by the interaction between them [43]. Even though a large body of literature focuses on examining genetic factors, training programs and their relationship with athletes' performance, there is no unique formula which can make anyone become an elite athlete [44]. Nonetheless, the literature clearly points out that an athlete seriously dedicated to training is able to enhance his/her sports performance [45]. What is important to bear in mind is that authors conclude that training and other extrinsic factors are crucial for high-performance athletes, they cannot produce elite athlete on themselves as each individual is limited by inherited genes. In other words, well-designed training programs and favourable external factors enable an athlete to realise his/her sporting potential. In brief, elite athletes' performance is an outcome of the cooperation of genetics and training factors [44].

Determination of genetic predispositions is used in athletic performance prediction and an athlete talents recognition. However, individual genetics is a crucial determinant of athletes sporting potential, the focus of this work is on the characterisation of what concludes a high athletic performance namely in kickboxing. It can be argued that kickboxing is a complex sport that requires involve a number of a particular characteristic to perform at a high-level [46]. It is a general understanding that to be able to provide insight into the competitive success in sports it is essential to examine elite-level athletes and their performance [47]. Comprehensive amount of literature focuses on the physiological characteristics of an athlete, which are measured by testing their level of components of fitness, and skill [46]. According to Houcine et. al [48], to determine a kickboxing performance it is important to investigate differences between winners and losers in physiological, physical, hormonal, and technical and tactical parameters. Nonetheless, the study discovered that elite kickboxing competition does not discriminate between winners and losers in terms of above-described parameters. However, if one athlete would have any of the components visibly at a lower level it would mean for his competitor major advantage.

Silimani [46] defines an athletic performance involvement of fitness and skill related components. Fitness components involve muscular strength, muscular endurance, cardiorespiratory endurance, flexibility and body composition, where skill related components are composed of agility, power, balance, coordination and reaction time. The main components involved in combat sports are technique, strength, aerobic fitness, power and speed [46]. Last but not least, the psychical condition of an individual plays important role in any sports performance. There are different factors of psychological characteristics which are especially crucial in sports these are namely motivation, self-confidence, and mental toughness.

The kickboxing performance in this study is split according to Silimani [46] into anthropometric characteristics, physiological profile, aerobic profile, anaerobic profile, physical profile (including strength, muscular power, speed and agility), psychological characteristics (including motivation, self-confidence and mental toughness). Further, to above performance profiles are added technique and tactics profiles.

Somatotype and body composition

Kickboxing same as other combat sports divides fighters into weight categories to link competitors with similar body properties, which creates concern for optimal body composition. For example, when competing in a specific weight category, a fighter should adjust his/her weight precisely at the limit of the upper boundary as higher weight differences result in an uneven fight. It is because in general higher weight means higher strength. It brings us to describing athletes somatotype, which is an expression of an individual's morphological structures. Carter [49] defines two basic types of human body, which are an ectomorph, mesomorph, and endomorph types. An ectomorph type is characterised by thin low fat or low muscle body build. On the other hand, an endomorph type is determined by high body fat. Between those two types resides mesomorph body type that is typically well-developed and a musculoskeletal robust build. Typically kickboxing is more suitable for predominant mesomorphic with a reflection of ectomorph component body types. In other words, kickboxers have usually profile that accentuates very high muscularity, low linearity and low body fat [46]. This can be illustrated on an example of two fighters with the same weight but different somatotype an ectomorph and mesomorph. As mesomorph type fighters would most likely have shorter limbs, which places them into a disadvantage as to impact their opponent they have to get to a closer range while their opponent is already able to land strokes. Nonetheless, if the opponent with longer limbs is unable to retain the ideal range the advantage passes to the shorter limbs fighter as he can utilise the power of short-range hits. These somatotypes vastly influence competition tactic and into some extent technique. In any event, fighters need to cooperate well with their bodies as they have to endure a high tempo of the match till the end, which is enabled by an aerobic and anaerobic system.

Physiological profile

To be a successful fighter in kickboxing it is essential to possess well-developed physical fitness and technical and tactical skills. To be a successful fighter in kickboxing it is essential to possess well-developed physical fitness and technical and tactical skills [50]. As a result of kickboxing combat that has high-intensity rounds with relatively short breaks, in which a fighter is not able to fully recovered physical state for the next round, it requires moderate to high level of aerobic and anaerobic power [46]. The anaerobic system powering fighter with bursts of energy to execute short and intense strokes with maximal power, while the aerobic system enables an athlete to repeat the actions with the same strength and speed for the duration of the competition. Further, the aerobic system provides optimisation of the recovery process during breaks between rounds and reduced effort during the fight [51]. To be a successful fighter in kickboxing it is essential to possess well-developed physical fitness and technical and tactical skills [50]. As a result of kickboxing combat that has high-intensity rounds with relatively short breaks, in which a fighter is not able to fully recovered physical state for the next round, it requires moderate to high level of aerobic and anaerobic power [46]. The anaerobic system powering fighter with bursts of energy to execute short and intense strokes with maximal power, while the aerobic system enables an athlete to repeat the actions with the same strength and speed for the duration of the competition. In addition, the aerobic system provides optimisation of the recovery process during breaks between rounds and reduced effort during the fight [51]. As in kickboxing combat are used both aerobic and anaerobic system training programs should be compiled to optimise each. Further, appropriate psychological preparation, rest, nutrition and improvement of kickboxing skills are into some extent ways to train metabolic pathways and skeletal muscles [46]. To better understand physiological demands it is important to describe functions of aerobic and anaerobic systems, which can be found in subsection called physical abilities.

Physical profile

To success in kickboxing, an athlete has to possess an adequate level of *strength* in both upper and lower limb [47]. Another essential of athlete to be able to participate in combat is the ability to express a dynamic strength. In other words, training of these abilities supports the improvement of the kickboxing performance. However, both types of strength isometric and isokinetic are generally acknowledged as signals of strength in kickboxing [46]. Subsequently, strength and strength endurance is required to enable a fighter to execute and maintain technical and tactical steps in combat such as punching, kicking, blocking, holding and pushing [52]. All thing considered, one of the essential attributes in kickboxing performance is the upper limbs isometric strength. The further detail on strength can be found in the above chapter 2.2.1,which concerns with physical abilities.

Muscular power is an integral part of a physical profile which governs the generation of a high volume of power in a relatively short period of time. The essential technique toolbox for kickboxers includes kicking and punching and to be an effective fighter; these essential tools require a high level of speed and power. Machado et al. [53] address the capability of generating high muscular power as a fundamental predisposition of amateur and elite fighters to achieve high-level performance. Kickboxing is a highly dynamic sport, and brief actions such as attacking and defending occur over a very short span of time as such they are supplied by ATP system. As an example can serve the period of individual punches which ranges within 50-250 milliseconds, hence it is crucial to acquire a high explosive strength/rate of force development [52].

Physical profile - speed and agility

Generally speaking in martial arts to be able to strike your opponent or defend against his/her attack it is vital to realise offensive or defensive technique in the right time. In kickboxing, timing is a vastly important factor as to be able to score a point a punch or kick has to land to an unprotected body part, which is possible only if the opponent does not expect a specific technique to occur. In other words, the realisation of technique in the correct time surprises the opponent and the fighter scores a point. To have a right timing means that a fighter has to react in the right situation within a split second and realise the strike with proper speed to land the punch otherwise the opponent can block, parry or counterattack. To develop appropriate timing, it is essential to train speed, reaction, and learn various sparring situations [46]. Defensive techniques and counter attacks are even more difficult and skill-demanding. They require precise timing, speed, and decision making such as what technique is the best for the particular moment. These can be developed only through intense training [54]. Speed can be described as an object overcoming fixed distance in the shortest time possible. It is composed of two phases, which are acceleration and maintenance of the speed.

Contrary, agility is an ability that concerns the speed of a whole body movement. The agility represents changes in velocity or direction to given stimuli. These changes include not only acceleration but also deceleration [46].

Agility is not only an ability of speed but what is more; it is an ability to process information, assess them, and react on changed situation accurately in the shortest time possible.

Generally in combat sports dealing with stress before, during, and after competitions is a common concern for all fighters [55]. The stress is elevated not only by a matter of worrying about the result but also from the fact that the actual combat will most likely produce some level of pain and in some cases injury. For that reason, there is a need for stress management. Nonetheless, to manage does not mean to eliminate it as stress within boundaries enables athletes to reach their maximal performance. This is supported by classic research in psychology, which finds that an optimal level of stress improves cognitive and motor tasks [56, 57]. To sum up, in kickboxing, fighters perform under a high amount of pressure. Therefore, psychological characteristics typically play a major role in separating successful athletes from the less successful counterparts [46, 55]. Many studies provide evidence which establishes a connection between psychological characteristics and sports performance. In addition, they supply number of psychological variables influencing athletes' performance [58–61]. There are variables composed of psychological skills such as concentration, relaxation, goal setting, controlling anxiety, and self-talk [58]. Further, there are other variables which concern personal and character determinants. These variables are mental toughness, self-confidence, and motivation [46, 60, 61]. The studies identified that physiological skills measures were a discriminator of a high-level kickboxing performance.

This is supported by elite athletes who describe themselves to be more motivated to achieve success in their sport, which has shown results in athletes' higher self-confidence. Further, athletes with higher self-confidence encountered a lesser degree of anxiety, prepare their minds through internal and kiaesthotic mental preparations, which enables channel their focus on their own performance and successfully use their concentration [46]. In summary, psychological skills play an important role in athletic performance.

2.2.4 Athletes' Performance Testing

To prepare elite athlete, it is essential that the training programs are based on well-designed research findings and recommendations, which will enable athletes to develop their physical abilities and technical and tactical skills more rapidly and to their full potential. However, no training program is perfect for every individual, and that is a reason why it is vastly important that the athletes' performance is regularly checked and the training program is altered accordingly. It is essential to bear in mind that physical abilities on its own are not possible to measure, but it is possible to measure their manifestation.

Athlete's performance is typically checked through motoric tests. These tests are consist of exercises defined by specific tasks which have robust rules. These test exercises can vary from elementary tasks as pressing buttons to more complex series of movements combinations or cyclical activity performed over a period of time [26].

According to Pavlik [62], motoric tests are used for training program management (checking if a training program is fulfilling expectations), finding out quality and level of athlete's physical abilities and their relation to the specific sport. Also, the tests are not used only to diagnose present but also to predict a future athlete's performance [63]. A test typically consists of a subject of evaluation (usually physical ability, or specific skill), measuring equipment, test procedures, rating scales, and athletes who are under testing. There is an enormous number of performance tests, and each is executed differently. For example, some tests are measuring a specific part of a physical activity where others are measuring its final results. When creating a performance test for athletes, it is important to choose the right parameter to measure, its units and scale, as without it the results could be hard to represent or could have low accuracy. Typical instruments for measuring given parameters are stopwatch, pedometer, or more complex measuring equipment [26].

Mekota [27] divides athletes performance testing into physiological tests, motoric tests, and sport specific tests. Physiological tests typically investigate responses of an organism to a particular load, stress, or other stimuli. Motoric tests serve for investigation of realised performance. Last but not least, sports tests deal with the examination of competition performance.

In general, sports performance tests can be divided into laboratory tests and field tests; however, there are many other categorisations. For example, Heller and Vodicka [64] define two categories, which are corresponding to energetic coverage of the tested part of a performance, namely aerobic and anaerobic. Sports performance tests can also be divided according to the type of exercise load, which can be static, dynamic. Finally, tests can also be classified according to load intensity such as maximal, submaximal, or supramaximal. The structure of motoric tests according to Mekota and Blahus [65] can be seen in the illustration below.

Furthermore, there is a need to mention that even though laboratory tests provide more accurate results and a high level of standardisation, in practice, field tests are used more often as they are more straightforward to use and require only a fraction

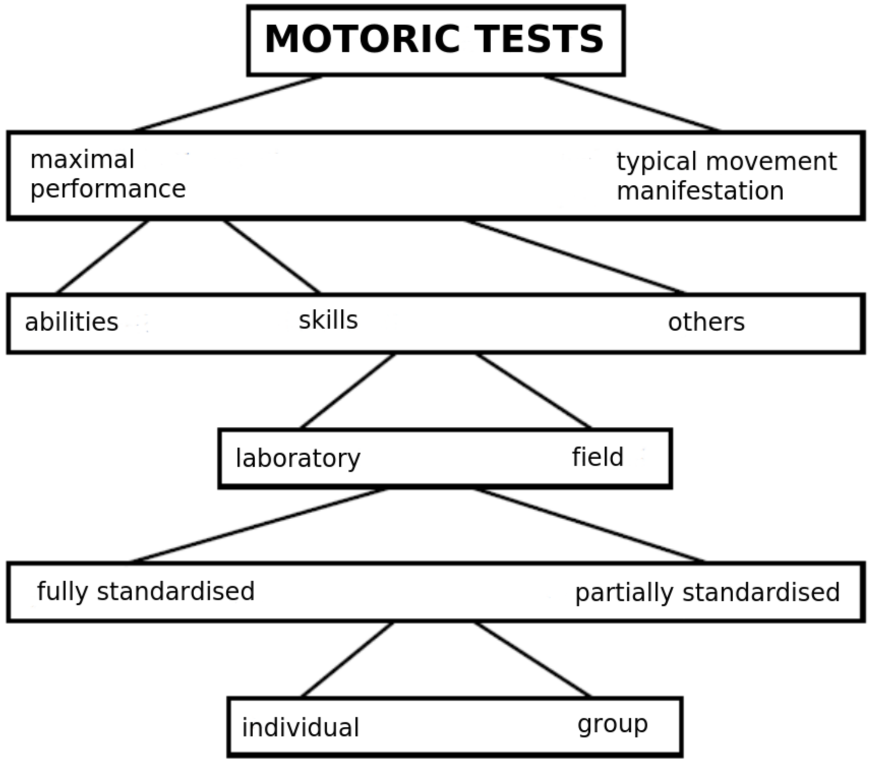

Fig. 2.5. Breakdown of motoric tests structure [65]

of resources. Field tests are widely used across practice their results are influenced by multiple factors such as athlete's motivation, external factors such as weather, which can result in an inaccurate representation of the tested ability. However, when testing, there is a relaxation of these factors as it is not feasible to account for all internal and external factors, which influence the test results [27]. The next step is to determine the **testing systems**, which can be described as collections of tests clusters that outlines a specific unit and are submitted at once. Each test cluster is combined into a test battery or test profile.

A test battery is composed of a test cluster where each test is standardised and compared against one criterium [26]. Each battery test result provides a score, which is at the end of all tests combined and produces the total battery result. There are two types of testing batteries homogeneous and heterogeneous. A heterogeneous battery aims to increase the validity of test results, by introducing multiple unique and little correlated tests. A purpose of homogeneous batteries is to increase tests reliability. On the contrary, a test profile and its tests are defined more freely. Further, the test profile results are interpreted individually, and typically the cumulative result is not given [66].

In testing theory, the main concern is a compilation of tests with appropriate parameters, which are typically represented by appropriately chosen value based characteristics [65]. The basic parameters of motoric tests are objectivity, reliability, and validity. When considering test validity, there is a need to consider the criterium with which we interconnect the test as the test can be suitable for one criterium but can be inapplicable for others. Essentially, a test criterium determines the test purpose and the scale of its measurement [65]. Further, test validity determines the accuracy of the chosen test [67]. The test validity is given by validity coefficient, which is represented by a variable labelled r_{xy} acquires a value ranging from 0 to 1. The closer to 1 the coefficient gets the higher reliance of the test is.

One of the most used validity coefficients is the coefficient r_{xy}, which is determined by the absolute value of correlation between the test X and criterium Y. This coefficient is sometimes labelled as r_{tc} (test, criterium). The r_{tc} provides the proximity of their linear relation [65].

Reliability regards the accuracy of test results or the size of a measurement error. Its aspects are stability test's scores in time, which is supplied by reiterating of the test, test scores equivalents determined by variation of test forms, and objectivity that refers to the independence of test's scores on the person in charge of a measurement. According to Neumann [67], high reliability of a test is proven when in a recurring athlete are measured approximately the same results. Nonetheless, even though a high-reliability test can have in some cases low validity. This can be caused by testing errors, which can have multiple causes such as instability of a testing environment, instability of tested athletes' performance, and instability of used measurement tools. Nonetheless, testing errors are typically caused by fractional elementary mistakes in testing, which are caused by a multitude of factors and inaccuracy. Significant errors occur by the disobedience of testing commands or by inattention during the testing [65].

2.2.5 Sports Training Planning

Planning is one of the essential parts of the management of sports training. Planning in sports training considers and secures all elements and connections specific to sports preparation. Further, it is a creative process, which is based on theoretical knowledge, general and sports specific practical experiences [68]. In planning, it is vital to establish realistic goals, tasks and methods of their reaching, which are outlined by scientific findings and practice. To reach established goals there is a need for continuous examination and evaluation of the plan, which has to be designed in a specific and straightforward manner to enable its easy management. After the plan execution, observed results are used as input for further planning, which makes it a long-term and never-ending process [62].

According to Peric and Dovalil [25], training plans can be divided according to the length of the training period. The first type of planning is called perspective plan, which is based on the prediction of an athlete's performance development. This type of plan decomposes the training goals into individual phases on the basis of realistic reflection of what is possible to achieve. The second type is conceived into a program composed of macrocycles, which includes individual elements essential for the management of a training process. The third type called an operative plan describes requirements of a year cycle into mesocycles and microcycles.

The microcycle plan is representing the most critical type of plan as it is a representation of a concrete form and enables to make operative changes according to training needs. The last type of plan is preparation for individual training units. This preparation involves determining the training unit targets, essential tasks, structure and content.

In brief, the planning process plays an integral role in maximising athlete's performance. Further, it is crucial that a coach and a trainee divides the planning process into discrete and manageable units, which includes both short and intermediate goals. This division of the plan improves the systematic structure of training for the athlete [69]. There are different ways of dividing the training as an example can serve the Olympic cycles which are made of cycles lasting four years. Nonetheless, the most currently used method of planning is structuring training plans into annual cycles, which is closely introduced in the next section.

Annual Training Planning

The annual plan and its training phases are important instruments used for utilising an athlete's physiological performance, which is essential for high-level sports specific performance [70]. There is a need for a progression of training demand from phase to phase, as without it high-level performance cannot be accomplished. The primary goal of training is to achieve an athlete's maximal potential at a particular point in time, which is typically the main competition of the season. To be able to reach the appointed target, the athlete's physiological performance has to improve at the right time to ensure the utilising of the athlete's performance [70]. The athlete's competition peak performance demands a synergy of skills, physical abilities, psychological traits, well-planned nutrition, and fatigue control [70]. With this in mind, the best strategy to achieve these goals is to adopt training periodisation, which is rationally compiled and competently sequenced. Periodisation is a topic of the next section, where it will be closely discussed.

The annual training cycle is typically breakdown into three phases which are preparatory, competitive and transition. Further, preparatory and competitive phases are composed of phases which have quite different purposes. The preparatory period is divided into the general and specific subphase, where competition period includes a short pre-competition subphase [69].

Moreover, each of the phases is formed from macro and micro cycles, which have particular objectives that are defined to achieve the general objectives of the specific period and the annual plan [69].

Sports' performance is dependent on the organism's adjustment and psychological adaptation to the specifics of training and competitions, and accordingly improvement of an athlete's skills and abilities [71]. This means that to increase an athletes performance to the planed level, it is essential to reflect the organism's adaptations during the planning and allocating the training phases duration. Consequently, it can be understood that the main criterium of allocating durations to individual phases is the competition calendar. The athlete puts maximum effort into the training process, which is lasting several months, that enables him to reach the best shape on those dates, therefore, the highest level of performance. The fulfilment of the goal in the main competition provides the assurance of a well organised and planned annual cycle [71]. The periodisation concept enhances the organisation of the annual plan and by it promotes a sequential approach to the growth of the athletic form. The need for periodisation is arising from the physiology as the development and perfection of skills and physical abilities can be achieved only through a long period of time. Further, the maximal physiological and psychological potential cannot be maintained through the annual cycle [69].

Another reason why the periodisation is needed are specifics of an individual, such as psychological and physiological abilities, dietary habits, regeneration, etc., but also climatic conditions, which in many sports such as ice-hockey, rowing, skiing, etc, play the definite line of each period [71].

As it can be understood competition period is a challenging phase, that brings high-intensity training and climaxes by the main year competition/s, which bears with it a high deal of stress [71]. Despite the fact that coaches and athletes are trained to cope with stress, the period of highly elevated stress levels should not last long. Training programs require alternating of stressful periods with recovery phases that decrease the athletes' stress level and enable their regeneration [72].

Periodisation

According to Bompa [70], periodisation is the base for building an athlete's training program; therefore, it is one of the crucial concepts of training planning. Periodisation can be defined as dividing time into smaller more manageable segments called phases or cycles [73]. These segments serve to different purposes, which facilitate a development towards a common goal. Kiely [74] looks at the periodisation as a term that defines training programs which have a form of predetermined sequential chains of clearly focused training periods.

There are numerous periodised designs such as linear, non-linear/undulating, block, fractal and conjugate sequence [74, 75]. Even though all of the variations of the training design vary in structure and supporting reasoning most of them sharing following axioms: i) There are preexisting phases for development and retention of particular fitness utilisations. ii) Fitness attributes should be trained in a sequential hierarchy. iii) Proven training structures, time schedules, and development projections can be generalised across sports subgroups. Consequently, two assumptions follow which are: a) The athletic performance and its biological adaptations can be predicted and suitably scheduled, therefore b) a suitable future training can be appropriately forecasted [74].

It is essential to bear in mind that no athletes are identical in their biological traits and as such identical training plan will always elicit a unique training response [74]. It results in forecasting with high precision is unlikely. On the other hand, when a plan is individualised and created by experienced coach an approximate improvement in an athlete's performance, with relatively high precision, can be outlined. Furthermore, periodisation introduces structured planning into training programs and as such enables to evaluate and revise them. Also, when used repetitively the precision of training outcomes forecasting should increase over time.

Nowadays, the emphasis on long term planning process is increasing, which is caused by initiative to bring young athletes in future to their maximal potential performance for competitions such as world championships [69]. When designing training programs coaches need to design an effective training program without causing an athlete's overtraining. To find this fine line is demanding and if the line is crossed it can result in ending a career of a promising athlete. Periodization is one of the tools that help to avoid this critical point [69].

Periodization originates from a desire to create training planning method which would manipulate General Adaptation Syndrome (GAS) theory to generate systematic plans that will enhance athletes' physical progression and avoid overtraining. GAS is a theory that defines a human body ability to adapt to a variety of stress factors linked with exercise programs that manifest in three phases. The first phase is called *shock* phase refers to an initial period of the training program, which approximately 3 to 4 weeks; this period is most of all neurological adaptation to the stress that is enforced to an athlete's body [76]. *Super compensation* phase is the second stage of GAS. In this stage, the athlete's body acclimates to physical activity stress in the form of skeletal, muscular, cardio-respiratory and what is more biochemical alterations [76]. These body adaptations advance until the athlete reaches the defined goals of the period or when reaches the optimal performance during competition. The third GAS phase is called *maladaptation* stage which refers to negative effects on the performance if entered. In other words, in this stage, an athlete is getting to the overtraining phenomena that represent physiological and psychological staleness and/or exhaustion [76].

The periodisation takes advantage of the GAS and creates a systematic training plan, which is composed of periodisation cycles. A cycle called macrocycle is the top abstraction of the plan and states the overall training period, which is typically one year in future. One macrocycle includes a series of mesocycles that last from weeks to months which is dependent on the goals of the mesocycle and the athlete's progress [76]. The number of mesocycles is dependent on the number of targeted competitions and level of fighter experience and can vary from 2 to 4 cycles. Further, the mesocycle is often split into several shorter periods called microcycles, which last about a week.

As mentioned earlier the periodisation has several different designs, which are used in different sports. As this research is applied to a specific sport namely kickboxing, it has been decided to use linear periodisation that is defined by coaching literature of AIBA organisation. AIBA is an international boxing organisation that governs boxing in all of its forms. The reasoning behind using boxing coaching literature is that both martial arts have similar sports preparation, division of competition season and the material itself is of high quality.

Typically, the dates of main competitions are known prior to the start of the season and rest of the competitions are announced at least three two to three month in advanced. The known dates of competition make possible to divide the calendar year into specific periods that represent a particular preparation. These periods or cycles differ in types of training units involved, and especially their intensity and volume. As an example can serve comparison of the beginning of the season when is usual to build strength and endurance abilities wherein the later stage is typical to build muscle explosiveness. In other words, each of the macrocycle parts is arranged in particular order, which corresponds to the need to develop particular abilities in that particular time. Nonetheless, the cycle duration can vary, which is a result of variation in competition dates year by year and most importantly by an athletes needs. Similarly, the determination of season beginning cannot be concretely defined as it is a matter of not only the competition plan but also by athletes current state and his/her fitness level.

on the other hand, Martens [77] views August as the most important month of the year as he states that it is the opening month of season training.

The beginning of season starts with the preparation cycle which is climaxing by competition cycle that usually finishes in December. After the athlete enters a short period of vocation or he/she directly transfers to the transitional cycle that continues till August or beginning of preparation for next season. The figure 2.6 presents conceptual model of 1-year dividing into 2 mesocycles, which is used by European Group in boxing [39].

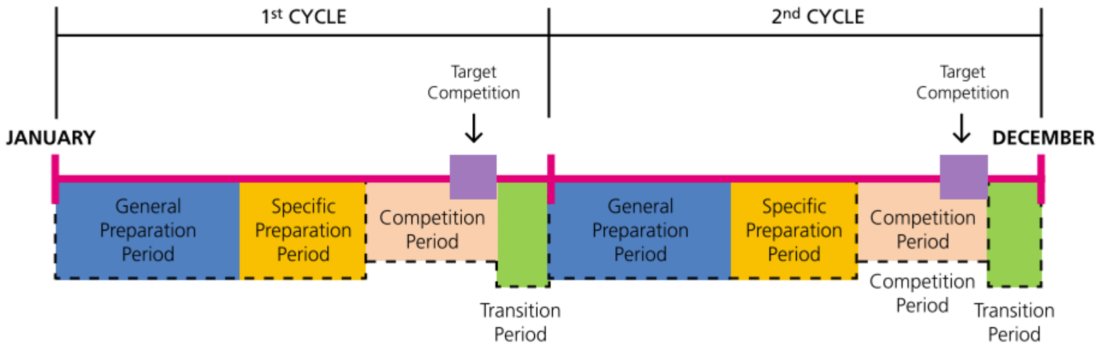

Fig. 2.6. Sketch of 1-year training plan of European Group [39]

The preparation cycle as its name tells it is a period in which an athlete physically, technically and tactically prepares for the upcoming competition period. This period is split into two sub-cycles [39]. The first sub-cycle is called general preparation, which is focused at physical preparation of a fighter. The second sub-cycle is called specific preparation period that concerns not only physical preparation but also the athlete's sport-specific skills (technique) and tactical preparedness.

As stated above the **general preparation** is characterised by the development of physical abilities such as endurance, strength, speed, coordination, and flexibility [39]. These abilities are outlining the spine of an athlete's success and the capability to reach his/her competition goals. It is important to highlight that this sub-cycle is highly concentrated at developing the aerobic system and a high level of strength. The reasoning behind the development of the aerobic system and stamina is building of sufficient aerobic base for further training. The high volume of aerobic training enables to improve a long-term energy system that is reflected in general endurance. The endurance is determined by the transport system that is a complex of organs and their mutually successive functions. Well developed transport system provides an improved supply of oxygen and energetic sources to working muscles. Last but not least improves the clearage of waste products which are flushed to the organism by physical activity. In other words, it helps to dispose of CO2 and other metabolites [78].

The most effective anaerobic/endurance training is running for that reason it is important to plan an athlete running plan during his/her preparation period. Further, the general preparation period is also concentrated on the development of maximum strength, which in later stage enables to develop muscle explosiveness. The maximum strength training mostly involves exercising with artificial weights. There is a need to highlight that according to coaching manual published by AIBA [39] it is important not to limit this period purely to physical abilities, to ensure variability in the training program. This means that a coach should also adopt several sport specific training units focused on technical and tactical skills. The training units typically last about two hours during this cycle which typically last about 10 to 15 weeks. This points out the setting of this cycle's training units, which should be of low intensity but of a high volume.

Specific preparation is a microcycle, which is a pre-competition period that is specifically designed for preparation for a targeted upcoming fight or tournament. Even though, this period is relatively close to the competition date it is still mainly focused on developing physical abilities; however, it is combined and trained through boxing movements, techniques, and tactics. This period typically lasts between 5 to 7 weeks but can vary according to the year competition calendar. There are usually two training units per day that last about 1.5hours [39]. During the specific preparation, the training unit intensity should increase and their volume decrease.

Competition cycle is the climax of the mesocycle which typically begins 2 to 3 weeks before the competition and ends by its last day. The focus of this period is on the shaping sport-specific physical abilities and skills, such as speed, explosiveness, techniques and tactics. There is usually one training unit a day, which lasts typically 1 to 1.5 hour with high intensity, but low volume load. The main reason for the low volume load during the training units is to reduce the tiredness of an athlete prior to competition [39]. During the competition period coach incorporates sessions which the main purpose is to prepare the athlete tactically and psychically for the upcoming fight/s.

As mentioned earlier the competition cycle is followed by **transition period/-cycle** which is purposefully created for the athlete's rest and regeneration. The transition period usually takes about 2 to 4 weeks, which is again dependent on the competition calendar. Further, the transition cycle is often split into two sub-phases, which are an active-rest and preparatory phase. The active-rest phase is concentrated at the athlete's restoration of the physiological and psychological state by relaxing and exercising other sports. On the other hand, the preparatory phase is used to integrate the athlete back into a training routine and prepare for the upcoming period, which involves the same type of training as the preparation cycle but with a lower intensity and lower amount of training units [39]. The athlete should use this time for healing any form of injuries, which occurred during the mesocycle. In the transition cycle, it is important to include sessions such as sauna, massages, stretching and compensation exercises.

To sum up, the periodisation is a useful tool which introduces a structure into the training plans but there is a need to highlight that it is important to approach the periodisation with flexibility. In other words, periodisation is a tool which facilitates a training path but the coach needs to be able to deviate from the chosen and consistently modulate it according to the athlete's needs and changing environment. Further, to provide effective training plans and training process it is crucial to constantly review relevant data and employ them to derive future direction [74].

3. SPORT DOMAIN

Roughly speaking, sport at a professional level is predominantly focused on the pursuit of the best possible outcomes in particular sports competition. Consequently, to be able to reach a maximum possible performance during competitions, it is vastly important to adequately train long before the competition takes place. Typically, top-level athletes are guided by coaches, who transfer them the training knowledge and experience in specific sport discipline through training programs. The coaches' know-how is exploited to prepare athletes physically, tactically, and psychologically. Training programs in sports consist of training units, which are sets of exercises that are performed by trainees in preparation for competition. Each training unit usually lasts from one to two hours. To get the best outcome out of a training process, it is essential to execute the exercises in a precise manner. Therefore, carefully planned training programs are imperative to reach the desired performance [3].

Typically, to be able to provide good quality and consistent training plans, a tool called an annual training plan (ATP), which is based on periodization, is used. The ATP can be described as a tool that is utilized as a foundation for all scheduled training activities over a year [79]. The training programs are periodical and athlete's macrocycle. Usually, a training year is typically divided into smaller, more manageable training periods, which is called periodization [80]. Each period is targeting development of different abilities, such as strength, endurance, speed, energy systems, technique, and tactic, with various proportions [81]. Further details of ATP and periodization are discussed in chapters 2.2.5 and 2.2.5.

There is a number of steps throughout which are training plans generated. These steps are as follows: (i) information gathering, (ii) analysis of previously executed plan(s), (iii) athletes' performance assessment, (iv) set the main events (competitions) of a year, (v) identify phases, and outline objectives of each phase, (vi) determine activities of each phase, (vii) identify exercise volume intensity and recovery time within a season, (viii) determine a total number of training hours to be complete, (ix) identify appropriate training units (exercises) for each phase [3]. To sum it up, to generate a successful training program, it is vital to evaluate the present and past athlete's performance, skills and physical abilities, define realistic goals (performance improvements) in a given time and compose training units that enable the athlete to reach those desired goals [3].

To be able to define training plans for athletes, there is a need to assess their sports performance, which is explored by research field called performance evaluation (PE). The sports performance is defined as a goal-oriented set of movements executed to perform a specific task and the process of its assessment is called performance evaluation [82]. The PE is involved in all sports as the PE is used to determine competitions' winners. Further, PE is crucial for training as, throughout it, performance improvement is observed. Correspondingly, PE is used to collect sport specific data that are later analysed for identifying errors in training programs, which leads to a possibility to their correction, therefore improvement [83].

Higgins [84] defines PE as complex process composed from a number of phases, which are as follows: (i) defining what should happen, (ii) outlining what has happened, (iii) comparing expectations with results, (iv) taking corrective actions if needed. According to Fairs' [85] PE is made of five steps, which are (i) data collection, (ii) diagnostics, (iii) prescribed plan of actions, (iv) implementation, (v) evaluation. There is a need to highlight that PE is typically involved collection and assessment of an extensive amount of biased information about an athlete's performance [3]. Fairs define the data collection phase as the fact-finding part of the PE process through which the data are gathered without making any conclusion or interpretation. Further, he also argues that the data collection involved gathering both objective and subjective metrics and measures. Objective data are gathered by an evaluator using specific equipment for exact measurement, where an athlete supplies subjective data. There are various methods of performance measurement in the sports domain, which typically involve qualitative and quantitative analysis of human motion, coaching methods and biomechanics [3]. The qualitative sports performance analysis is done by visual observation of human motion, which is executed by evaluators. The accuracy of the analysis is depended on the equipment involved and evaluators experience with its usage. On the other hand, the quantitative performance analysis relies on objective data retrieval and analysis of a biochemical motion profile. Nonetheless, quantitative performance analysis is vastly demanding on time resources as it is in most cases, a manual process. Consequently, there has been developed several computer systems that increase the speed and quality of PE [83]. A large proportion of these systems are built to capture a whole picture of an athlete's motion in digital form. Later, the collected data are fetched into a computer and analysed. This opened the door for utilisation of AI techniques. The AI is making its way into the sports industry; however, it is still in its early stages [86]. Generally speaking, it has only limited capabilities regarding performance evaluation. This is due to the lack of formal definition in terms of quantification of sports science. Similarly, it was an obstacle for this research, which had to be addressed.

As this research is focused on applying automated planning on sports domain, the quantification of sports performance is a cornerstone for this research. To be able to quantify performance, there was a need to develop a scheme, which would allow us to breakdown the performance and compare athletes and their abilities. More importantly, this scheme enables us to define the vital parts for the domain, such as initial state, goal state, preconditions, and actions' effects. Further details can be found in the next chapter. As a next step, after defining the sports performance quantification used in this research, there was a need to define annual training plan requirements. which allow us to incorporate them into the domain.

3.1 Sport Performance Encoding

The crucial construct in defining the sports domain is a sport performance that is a composed of three main aspects, namely physical, technical and tactical performance, where the physical performance is the main motivation of this research.

To clarify, the focus on the physical performance flows from the fact that it is large proportion of overall performance and it also majorly influences the technical and tactical performance. Further, it is based on objective data, which allows us to encode realistic picture of the athlete's performance.

In terms of planning, there is a need to describe real life objects on which the planning system will simulate the effects. The overall object is an athletes body. The

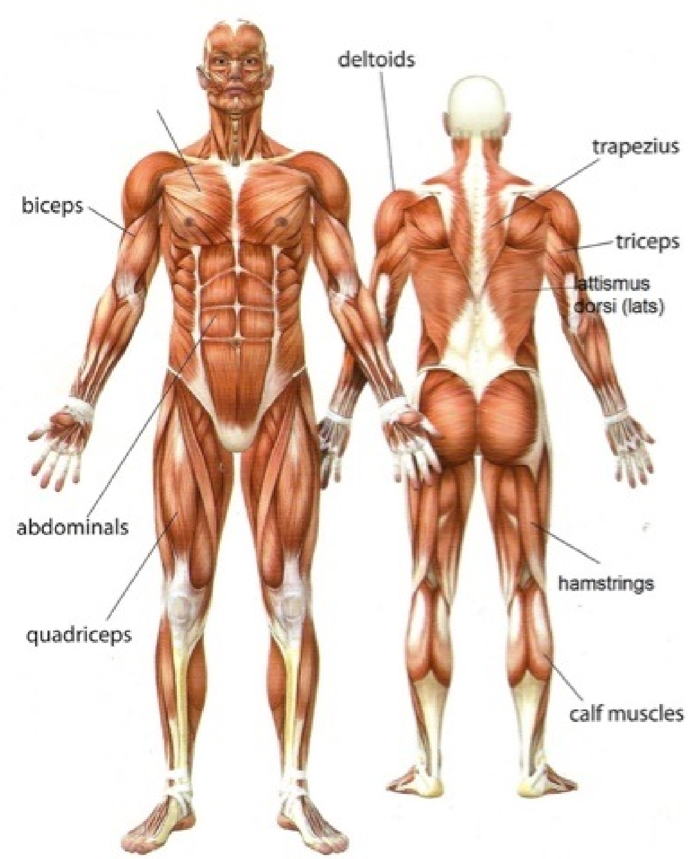

Fig. 3.1. Basic human body anatomy [87]

body was divided into several abstract groups as defining individual muscles would not be feasible as it would require excessive time resources. Also, the research purpose would not benefit from encoding of individual muscles as it would add unnecessary complexity not only for the author but what is more for the coaches who will define the problem files. To continue, the separate body groups are upper limbs, middle body, and lower limbs. Upper limbs middle body and lower limbs are further divided into individual parts, which can be seen in the figure 3.1. The figure shows the main muscle groups in which is our domain interested in. The individual body parts will be used as types (objects) in the domain.

Next section 3.1.1 describes one of the main notation of sports performance, which are physical abilities. In addition, the next section is determining the concepts and their linkage to an individual body parts that will be implemented into the domain. Last but not least, the section 3.1.2 introduces this research sport performance quantification scheme, which provides us with an ability to quantify the sport performance and encoding it into our domain.

3.1.1 Body Properties

As this research is mainly focused at physical abilities part of sports performance, there is a need to break it down into specific requirements for the sports domain. There are two main parts of physical performance, which are energy systems and muscle abilities. To be able to define the domain requirements, there is a need to introduce each of physical performance parts individually.

There are two types of energy systems that produce and supply the body energy, namely aerobic and anaerobic systems [29]. The anaerobic system provides power for high-intensity exercises that last maximally 2 minutes. The aerobic system is the main supply of energy for the steady physical activities that last for a longer time. The energy supplied by the aerobic system is created with oxygen access, where on the other hand, the anaerobic system is producing energy without it. Both of the systems are in discussed in detail in the chapter 2.2.1. Both of these energy supplies influence into some extent all athlete's physical abilities. As a result, they were identified as properties of the whole body. In other words, the energy systems values are not applied to individual body parts as defined in chapter 3.1, but rather on the abstract body object.

Further, the chapter 2.2.1 also defines in detail endurance, speed, strength, flexibility and coordination abilities, which further specifies demands on the domain. According to Dovalil and Peric [25], these body characteristics can facilitate insight into muscle abilities, therefore into sports performance. Endurance in the context of abilities defines the capability to perform a physical activity over time. Further, it dictates the recovery time in which an athlete is ready to execute the next exercise. The endurance is mainly a function of the energy systems, and as such, it is incorporated into the domain model. Athlete's speed determines the ability to perform a physical task in the shortest time possible. The task has to be performed with the highest intensity, with low to none resistance. Comparatively, with endurance, the speed is dependent on the anaerobic system, but it is mainly determined by explosive strength. Speed is, in our domain context, included in explosiveness, anaerobic, and purely speed oriented training units. Strength can be identified as an ability to execute a physical task with a great deal of force and is directly connected with muscle function [27]. Strength can also be seen as an ability to overcome resistance throughout muscle tension. The strength is viewed by several authors as a central ability for successful sports performance [36–38]. The strength is categorised into four types of strength, which are absolute strength, speed strength, reactive strength, and endurance strength. As strength is the central piece of physical abilities and typically its categories are specifically targeted, they are incorporated in the domain as a body parts' properties. Maximal strength and endurance are defined individually but reactive, and speed strengths are connected in the same body part property called *explosiveness*. Further, *explosiveness* attribute also incorporates the speed ability. The reason of connecting these separate abilities into one value is that all three abilities speed ability and reactive and speed strength are intertwined and they are usually trained as one overall ability often referred to as a speed training. Besides, the maximal strength is addressed in the domain as *strength*, where strength endurance is named by its full name, which has been done to avoid confusion with general endurance. In short, our domain representation of muscle abilities is determined by maximal strength, endurance and explosiveness.

Flexibility and coordination are not explicitly defined in our domain as we are assuming that those abilities development is included in most of the training units. For example, flexibility is exercised before and after each training unit as it is crucial to avoid any injuries. In addition, coordination is applied through every training unit as each training unit involves multitude of different exercises. Further, technical and tactical training in kickboxing is demanding on coordination abilities; therefore it develops it.

After we defined the properties, which are used to determine the athlete's progress, there is a need to attain their numeric value. This was accomplished by a sports performance quantification scheme, which is introduced in the next chapter.

3.1.2 Sport Performance Quantification Scheme

As the above chapter describes, we define an athlete's physical sports performance through five different properties, which are aerobic and anaerobic system, maximal strength, strength endurance, and explosiveness. Nonetheless, there is still a need to identify value-based representation, which will enable us not only to determine the level of each athlete performance but also it will enable us to compare athletes between each other. The need for having value-based performance quantification flows from the automated planning as it requires us to determine the initial state of the athlete and also the effects on the body of each action applied. There is a need to highlight that the planning actions are representing, training methods, and what is more training units.

For the above reasons, there has been developed a scheme that accomplishes these requirements. The scheme involves various tests that can take a form of laboratory or/and field-based tests, which are nowadays used to evaluate physical performance.

The novelty of the performance testing is not in the testing methods themselves, but it lies in the way how the testing results are evaluated. The problem with nowadays testing is that it does not provide an appropriate scale that would give a clear understanding of the performance and also a comparison between athletes.

At first, there is a need to define a test battery and its meaning. A test battery is a set of tests used for assessing and prediction of sportsman performance [26]. In this case, the test battery is composed in a way to determine a value, which will represent the current state of a specific ability of a particular part of the body. In other words, each test of the test battery will determine maximal strength, strength endurance and explosiveness of individual body part. Further, there is a test that assesses the level of body aerobic and anaerobic systems.

It is worth to note that every sport uses different performance tests specific to the kinds of workload involved during the sports performance. As this research uses kickboxing as a proof of concept, the test battery is utilised according to its needs.

It is vital to have in mind that not only different sports compose test battery in a different fashion but also experts in the same sports may differ in its composition. In this research, we provide an example test battery, which can be used as it is or could be used as a guideline for experts who would use our domain for their annual plans. In other words, it is encouraged to define a test battery to fit the needs of individual sports.

Our test battery consists of 11 tests. The first test is called cooper's test, that is dedicated to testing the aerobic system. The test itself is run in which an athlete needs to run as far as possible within 12 minutes. This test is well established in the sports community, and as such, there is a lot of material that can be used to transform the test results into an approximation of vo_2max which is the indicator of the body maximum oxygen consumption. The anaerobic system is tested throughout an exercise called burpees. Similar to the cooper test, this will be a number of burpees over time, which in this case is one minute. A burpee is a sophisticated high-intensity exercise that requires a large amount of energy. The activity itself has seven stages, which are displayed in figure 3.2 and are repeated as fast as possible within the time frame of the test. Even though the aerobic system covers some proportion of the energy the anaerobic system, the majority of it. The energy coverage and transitioning between each system can be observed in figure 2.4 provided in chapter 2.2.1. The next test is defining the strength endurance of upper limbs and is done through push-ups. This time is not limited by time, and the goal is to do the maximum amount. Nonetheless, it is essential that the athlete is performing the push-ups continuously without breaks. To find out the strength endurance performance of lower limbs and mid-body, we use squats, and sit-ups executed the same way as push-ups, therefore, continuous maximal repetition. Further, there is a need to find out the maximal strength of individual parts. The lower limbs are tested through squats with the maximal load. In other words, the squat is performed with an iron bar with weights, and an athlete should load a maximal amount of weight to execute one squat. Similarly are tested upper limps with the difference of using bench-press exercise, which is performed in a vertical position with the bar located above the chest. To test the maximal strength of the mid body, we are using one repetition of hanging knee raise exercise with maximal load. The last ability to test is explosiveness, which is verified by the standing long jump test for lower limbs, medicine ball throw test for upper limbs, and vertical leg crunches test for mid body. The standing long jump should be performed without the initial running phase. To put it differently, an athlete initiates the leap from a fixed spot and tries to jump as far as he can. Medicine ball should have the same weight for all tested athletes, and the purpose is to throw the ball into a distance. The last but not least exercise to discuss is the vertical leg crunch. The objective of this test is to perform as many leg crunches as possible in 10 seconds.

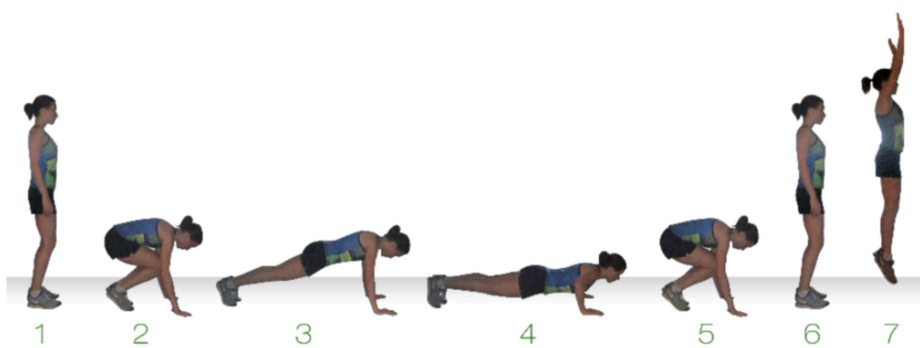

Fig. 3.2. Stages of Burpee [88]

The next step is to define the technique of placing the battery test result on the scale, which will provide us with normalised values that can be used in the planning domain. Further, the novelty of our approach to the test result is not in testing methods themselves, but it lies in the testing results evaluation. At the initial stage, there is a need for testing a group of athletes with the same weight group, gender, height, and if possible somatotype.

To be able to design the scale, there is a need for three results from the tested group, which will be taken into consideration. The first result is a case when the athlete is not able to perform a particular test. The second result is the approximation of the worst results achieved by athletes in the same group. Last but not least, the third result is an approximation of the best results. The range of the scale for the individual test will be from 0% to 100%, where the top boundary is representing the approximation of the best results and the low boundary is a demonstration of athletes who cannot perform the test. The approximation of the low-performance results will be used to provide insight into the improvement of an individual. In other words, this will show how much the athlete improved and how much he/she needs to improve to reach the top performance. After obtaining the scale, the rest of the results will be placed on it through a simple calculation, which is shown in the equation 3.1.

Further, these boundaries are based on approximation, which mean that with an increasing number of testing iteration, the evaluation scale will gradually improve its precision. The assignment of the individual values to the parts of bodies are derived from the testing exercises and muscle areas they concern. To give a better outline and understanding of the value assignment, the figure 3.3 displays the body areas that are employed during the push-up test.

As shown in figure 3.3, areas under load during push-ups are shoulders, breasts and abs illustrated by red colour [90]. Secondary areas under pressure are external oblique and rectus abdominis, which are muscles shown by the yellow colour in the figure 3.3. Push-up test (maximum push-ups in one go) provides us with a result of an endurance ability for the primary muscles under load. The secondary muscles will not be taken into consideration in terms of the push-up test as they are mostly assisting muscles for this type of exercise. These secondary muscles in the push-up test will be tested by different exercise.

Next, there is still a need to demonstrate the calculation for deriving the values which serve as a representation of a specific muscle ability for particular muscle groups. The example 3.1 and 3.2 provide simulated scale for push-up test and results for three athletes within the same tested group but different performances, respectively.

Further, the example 3.1 shows what values could represent the boundaries of the scale. It is vital to bear in mind that the scale does not reflect real test results, and as such, it serves for demonstration purpose only. The example 3.2 shows three simulated testing samples which are manufactured test data; nonetheless, they are based on authors experience and could represent real-world scenario.

Example 3.1. Push-up test result scale

Athlete unable to perform the exercise $\Rightarrow$ 0 push ups

The approximate of low performance result $\Rightarrow$ 16 push-ups

The top approximate result $\Rightarrow$ 80 push ups

0 $-$ 80 push-ups are represented by 0% to 100% (range)

Again, the lower boundary represents an approximation of testing results from multiple testing rounds of low-performance athletes in the specific test. These testing

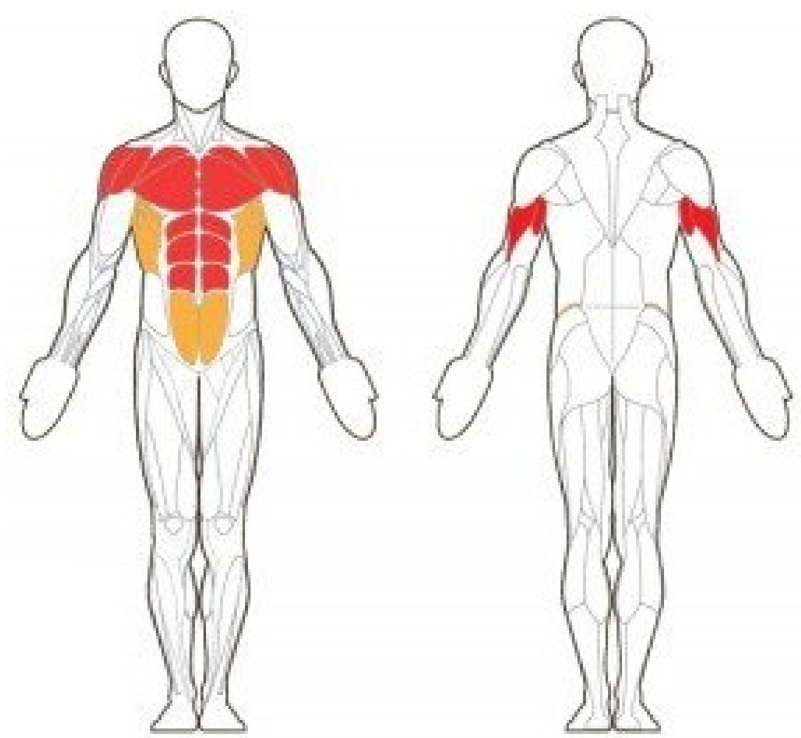

Fig. 3.3. Main and secondary muscle preforming during push-ups [89]

results will be in most of the scenarios reached by newly started athletes. The push-up scale was created in order to provide a simple scenario in, which we can show the workings of the performance calculation technique. In example 3.1, there is shown an approximation of low-performance results of 20 push-ups, which is on the scale equal to 20% of the top-level performances. In this simulated case, the differences between low and top performance athletes are 80%. This provides us with a performance range in which athletes performance should be located. The testing samples in example 3.2, are results of three individuals that have similar body structure (approximately bodyweight 80kg, and height 185cm), but all of the subjects are on a different performance level (low, medium, and high-performance level). These testing results will show a practical demonstration of the value assignment. In other words, these samples are placed on the scale and transferred into a percentage of a strength endurance of a specified muscles group. The testing samples are as follows:

Example 3.2. Examples of push-up testing results

1. **Subjects with higher physical performance level**

   Maximum of push ups on one go: 70x

2. **Subjects with medium physical performance level**

   Maximum of push ups on one go: 40x

3. **Subjects with lower physical performance level**

   Maximum of push ups on one go: 25x

The value needed for our planning domain is obtained from a simple formula shown in equation 3.1. Form the first 3.2 example, the first subject performed 70 push-ups, and as such, by the given values from example 3.1 and performance calculation provided in equation 3.1, it translates into 87.5% of the best performance. The second subject performed 40 push-ups on one trial that is according to the scale, corresponds to the performance of 50%. Last but not least, in the case of the third subject, the test result is 25 push-ups that are equal to 31,25% of the top performers.

Test results calculation

$$x = \frac{100}{n} \sum_{i=1}^{n} \frac{r_i - l_i}{b_i - l_i} \tag{3.1}$$

To obtain a more precise value of an athlete's performance, it is encouraged to use multiple fitness tests. The equation 3.1 incorporates such an option, which is illustrated by the summation of the test result divided by the number of tests. The sum of test results is represented by Σ, where n is the number of tests concerning a specific body part ability. Before summing up the resulted values, there is a need to transform the individual test results into the percentages of the performance. This is done by subtracting the approximated low result l_i from the specific test result r_i and dividing it by the approximation of the best results b_i that is also subtracted by the l_i. After it is multiplied by 100, which gives us athlete's percentile performance compared to the top performances. The subtraction of l_i from the r_i and b_i is done in order to transfer the test result into a range with bottom boundary represented by l_i and top boundary represented by b_i. If the calculation results in negative value, it means that the test result was under the low results boundary, therefore, we assign to the physical attribute a zero.

The calculation of the performance should take a place after the testing of all athletes. The reason behind this is that if the calculation would take a place before gathering all test results some of the athletes could perform better than current best result. This would change the calculation for all of the previously calculated performance results. Further, the calculation should be performed once prior the plan execution and repeated in the end of the planned period. Nonetheless, there is a need for checking if the athletes performance is improving according to the plan. This should be done by repeating the performance testing every two to three weeks. In the case the improvement is not within boundaries of $\pm 3\%$ there is a need for re-planning. It is essential to bear in mind that during the check testing the initial testing value b_i is used.

On the final note, energy systems and muscle abilities are tightly coupled together and have a significant impact on each other. Nevertheless, they are individual abilities, and they need to be defined as such to enable us to address each ability by specific training unit. The next chapter introduces an annual training plan specification, which defines the annual plan features. Determining the specification is essential for creating training plans and later to be able to convert the characteristics of these plans into PDDL, which is subject of chapter 3.2.3.

3.2 Annual Training Plan Specification

This section serves as a formal description of the annual training plan (ATP) and at a later stage will be used for translating into PDDL. At first, there is a need to mention that ATP is vastly different from sport to sport. This is caused mainly because each variation of sport requires a different form of physical, technical and tactical preparation. Nevertheless, physical abilities are a foundation for most of the sports. Moreover, most of the sports share similar methods of training a technical and tactical aspect of it. The similarities between them give space for this research to develop and provide a domain, which will serve as a base for various sports. In other words, there is an intention to develop a general construct for ATP planning domain, which could be used with a majority of sports. However, every sports domain has specific characteristics, which have to be incorporated in each sport as these features enable producing high-quality plans. To be able to define the components of a specific sports theory, their conditions and other domain oriented differences; there is a need for vast experience in the particular variation of the sport. For that reason, the author is focusing on a specific field in which he holds several years of experience. The mentioned areas of experience are boxing and kickboxing. This domain will serve as a proof of concept and foundation for further interdisciplinary research concerning automated planning and sports theory.

The Chapter 2.2.5 describes the theoretical base for ATP, nonetheless, this chapter focuses on its specific adaptation in martial arts and defines it in a way to enable easy translation into PDDL.

The ATP is made of 26 weeks, which represents an athlete's training macro-cycle. Each week belongs to a particular period. Further, a macro-cycle has four phase namely general preparation, specific preparation, competition, and recovery period. Each week has a capacity of hours that can be assigned to a particular week. The volume of hours assigned is influenced by the phase in which is the week defined. Additionally, to each week are assigned areas of physical performance and intensity with which should be the training unit performed. The assignment of volume and intensity will be discussed in following chapters.

3.2.1 Training Intensity

The intensity represents the training unit execution level. In other words, the intensity expresses the effort which should be involved in the training unit execution. It has three possible states which are "learn", "maintain", and "develop". These effort attributes are allocated to a physical ability that should be trained in a particular week. Further, the intensity attribute is distributed according to a training period.

According to a chapter 2.2.5, the first period called preparation period is divided into the general preparation and specific preparation period. The general period usually lasts for 12 weeks, followed by specific preparation period, which typically takes place for six weeks. The purpose of the general period is to focus on all areas of physical performance [39]. The aerobic system is in the first six weeks trained in a "learn" intensity, which means that the intensity is low but with a high volume of hours. Explosiveness and strength endurance is trained in develop intensity for the same amount of weeks.

After the initial six weeks, strength endurance and aerobic system are no longer in the direct focus of training. However, the explosiveness is after the first six weeks switched for "maintain" intensity, which means that the training units have higher intensity, but with a moderate amount of hours. The smaller amount of training hours enables an athlete to regenerate and prepare for a later stage of training. The explosiveness "maintain" intensity lasts for three weeks. After these three weeks is an athlete prepared to adopt the "develop" intensity until the end of a specific period (approximately nine weeks).

The anaerobic system is trained after the initial first four weeks, which are mostly focused on the improvement of physical fond (strength endurance, stamina), till the end of the whole macro-cycle. The intensity of training unites developing anaerobic system is dependent not only on the physical state of the athlete but also on the period in which is the athlete situated. If an athletes anaerobic system performance is between 40 - 50% in the start of the general period than it is trained with learn intensity for several weeks till the system reaches at least 10% improvement [25]. When the required improvement is reached, the effort attribute is adjusted for the develop and performed until the end of the general period. In case the required performance is not reached, the intensity has to be set to develop no longer than three weeks before the end of the general period. This switch is necessary to prepare an athlete for the upcoming period, which is highly demanding for physical and psychical resources. Further, if the athlete is over 60% of the anaerobic performance at the beginning of the general period the training intensity increases to develop, but with the same volume of hours as intensity learn. Nevertheless, between this period, there are inserted two weeks of intensity maintain to give the body time to recover.

Last of the muscle abilities, which have not been discussed yet is the maximal strength. This ability is facilitated by "develop" intensity for six weeks during general preparation. These six weeks are divided into two segments. The maximal strength training starts after the first four weeks of the cycle, which is usually initiated by boot camp. Boot camp typically takes place in the fifth and sixth week of the general period. When the camp takes place, the maximal strength is practised for mentioned three weeks followed by three weeks break and then again it is trained for another three weeks. This should prepare the athlete for the rest of the season in terms of maximal strength improvements. Nonetheless, it is essential to mention that it is crucial to maintain strength abilities during the whole season.

During the competition period, there are trained only two areas of physical performance, which are an anaerobic system and explosiveness with intensity on "maintain", which means high intensity with a relatively low volume of hours. Competition period usually consists of five weeks, which peak by targeted competition [39]. The reason behind training only these two physical performance abilities on the "maintain" effort level is that the athlete needs to regenerate to be ready for the upcoming competition. Further, focusing on the anaerobic system and explosiveness provides an athlete speed that is essential for the competition. In terms of planning, it means that the five competition weeks are practically static when considering physical performance. Nevertheless, future work will extend the current model to include technical and tactical training. The recovery period is consistent of three weeks where an athlete has only one training per week, which is focused on regeneration processes of the body after the whole macro-cycle [39]. There is a need to emphasise that physical training is just part of the overall performance and that the technical and tactical performance will be addressed in the future study. The next step is to define the training volume for each macro-cycle week.

3.2.2 Training Volume

A training volume is a number of hours dedicated to a week for practice units. To enable easier translation of the domain into PDDL, the training volume is expressed by a ratios that define the correlation of the three abstract areas of the kick-boxer performance to the total available training hours. The defined ratios are *i*) technical ratio ρ_t, *ii*) muscle abilities ratio ρ_m, and *iii*) energy systems ratio ρ_e.

The volume ratios are depend on an athlete's performance type, boxing type, intensity attribute, and training period. In addition, the ratios representation will enable scenarios in which the individual has time constraints that would not allow putting in place the maximum volume of hours, which would provide the highest reward.

As mention above, there is a total volume of hours for each week that represents the maximum of possible practice hours that would be executed by an athlete. This number of hours is dependent on a training period but most of all on the time resources of each athlete. The available time resources are typically extensively different between amateur and professional athletes and as such, the number of hours has to be agreed upon prior running the planner.

As a next step, there is a need to define the types of athletes, which will outline the change in the available time resources. For our research, we decided to define three types of athletes. The first type is for people who want to lose weight or get into shape, which is called enthusiasts. The second type is for people, who are training for competitions try to reach some level of performance regarding competitions, which is addressed as amateurs or semi-professionals. Last but not least, the third type is dedicated to professional athletes, who typically live from professional fights and as such they can put as much time into training as is needed. Where the enthusiasts usually have a maximum of three training units per week, the semi-professionals can usually have 5 - 8 training units per week and professionals have usually two training units per day. Nevertheless, all three types of athletes have same volume ratios for the ATP, with minor differences addressed in the individual training units.

Another volume ratios influencing factor is a technical and tactical type/style of a boxer, which is specific for our chosen sport. There are four main styles in boxing/-kickboxing, which are out-boxer, slugger, boxer-puncher, and swarmer. Typically, the boxers in each style are having different strengths in different physical abilities. For example boxers who identify themselves as swarmers are often shorter athletes with very good physical fond and speed. Their tactics is to get on short distance and over come their opponent with fast high intensity attacks. In contrast, the out-boxer or technical-boxer typically seeks to maintain distance between the opponent by throwing fast long range punches. This type of boxer needs to have balanced physical preparation. The sluggers usually tends to lack technical readiness but makes up for it by raw power. The boxer-puncher can be seen as a combination of the three other boxing styles. Nonetheless, the boxer-puncher often lean to one of the above styles. As the boxing style of an athlete influences the creation of ATP there is a need for multiple adjustments of the domain according to it. For our domain we choose to create plans for out-boxer as the author of the study has vast experience as this type of athlete. There is need to highlight that defining the type of an athlete is domain specific requirement, which is derived from boxing and kickboxing.

It worth to highlight that the main influence factor of the volume ratios resides in dividing the total amount of hours according to the training period. As a next step, there will be presented the training cycle periods and its ratios, which incorporates all the influencing factors. Lets begin with the initial 4 weeks of the general preparation period, where the ρ_e is $\approx 60\%$, the ρ_m is $\approx 40\%$, which indicates that the main purpose of this period is to develop physical abilities. Furthermore, this period typically ends with a boot camp, which usually lasts one up to two weeks. During the camps the ratios are as follows: $\rho_e \approx 40\%$, $\rho_m \approx 30\%$, $\rho_t \approx 30\%$. During the camp, athletes are exposed to physically demanding conditions, which requires the ATP to provide a regeneration regarding physical abilities by lowering the total volume of hours directly after by 50%. Through the three weeks directly after the boot camp, the focus shifts from energy systems to muscle abilities and technical skills, which is in ratios reflected as $\rho_e \approx 20\%$, $\rho_m \approx 40\%$, $\rho_t \approx 40\%$. After this relative regeneration period, the number of hours increases by 50% of current total volume of hours until the end of the general period and the ratios change in order to prepare for the next phase which is specific preparation. The ratios changes for these last three weeks accordingly the $\rho_e \approx 30\%$, $\rho_m \approx 30\%$, $\rho_t \approx 40\%$.

The general period is followed by specific preparation, which is less focus on physical abilities and it is primarily concerned with technical and tactical development. The volume ratio during the specific period is vastly different between different sports, but it usually last about six weeks. As martial arts require a high level of technical and tactical resources, it results in a higher focus on technical preparation during this phase. Consequently, the volume of hours in means of physical performance training is reduced. More specifically, during the first half of the specific period the ratios are as follows, $\rho_e \approx 15\%$, $\rho_m \approx 15\%$, $\rho_t \approx 70\%$, although the total volume of hours is steadily increasing till the end of this phase.

Concerning competition period, an athlete has the same level of hours for training physical performance through the whole period. The ratio of physical performance over technical preparation slowly decreases till the peak competition. After the main event, the rate again rises to the same proportion as at the end of the general period. The whole cycle finishes by regeneration period which has standard of two hours a week.

This semi-formal definition provides us with enough background for translation into PDDL. The next chapter introduces the sports domain model.

3.2.3 Sports Planning Domain Model Specification

Throughout this thesis, the annual training planning (ATP) has been mentioned multiple times and discussed extensively. In this chapter, we present the formal conceptualisation of our sports domain model, which is based on ATP. Nonetheless, it pursues to deliver more than a training plan that is a general outlook of the macro-cycle. To put it in words, we aim to develop a domain model, which will intelligently choose a training unit or the primary training method and place them into a sequence. This sequence will represent detailed ATP, which will determine when the athlete has to perform the TUs according to the macro-cycle phase and the target athletes attributes [3]. This will provide the means to supply highly individualised training plans. This will be done by numerical planning, which is discussed in 2.1.1. To produce the domain model, we will encode it in a planning language called PDDL. The details of the language are provided in chapter 2.1.3.

From chapter 3.1, we obtained the specification of an athlete's performance and body proprieties, which provided us with a description of athletes physical properties that are represented as numeric fluents. There are two sets of these physical properties, one which defines physical abilities that are applied to a part of the body and the other which are applied to the body as a whole. The first set of athlete's physical abilities are the strength, endurance and explosiveness. Further, it is essential to mention the body parts involved, which are upper and lower limbs, and midbody [3]. The second set consists of anaerobic and aerobic systems. To provide a better understanding, the following overview of the main numerical fluents are provided:

(**explosiveness** $?x - body\_part$) represents the speed and explosive strength of an athlete. There are three fluents of this type according to the described body parts.

(**endurance** *?x - body_part*) is used for representation of the strength endurance of a body area represented by the $?x - body\_part$ type.

(**strength** *?x - body_part*) defines the maximal strength of a specific body area.

(**aerobic_system**) defines the state of the aerobic system, which is applied for the whole body and as such does not have defined $?x - body\_part$. This attribute provides an insight into athletes ability to sustain long low-intensity exercises.

(**anaerobic_system**) is a numerical fluent that defines the body ability to perform short to medium-lasting high-intensity exercises. The $anaerobic\_system$ fluent is also applied to the whole body.

Further details about physical abilities, sports performance, athletes testing, and kickboxing are provided in chapters 2.2.1, 2.2.2, 2.2.3, and 2.2.4.

The ATP is based on the concept of periodization as described in chapter 2.2.5, which divides the macro-cycle into smaller cycle focused at specified part of athletes' sports performance. Each period has a certain number of weeks, and each week has a certain level of intensity and capacity. A training week consists of several slots, which vary according to the weeks training volume (more on volume in chapter 3.2.2). To put it differently, the slots represent available space for a training unit (TU) in the training week [3]. In the domain the slots are represented by a predicate (*slot_in_week* ?*slot* ?*w*), where ?*slot* is the available space and ?*w* is the week number to which the slot belongs. Further, each TU or TU's primary training method can be scheduled into one or more slots, but no slot can have more than one TU. This is represented by a predicate (*action_allocated* ?*action* ?*slot*). The allocation of two TUs is not allowed as the execution of two training units at the same time is not possible. However, in some cases, it is allowed to schedule the same actions in two follow-up slots. The case, when the slot is free, is represented by a predicate (*free* ?*slot*). It is important to mention that there is a need to ensure the consecutiveness of the TUs. The consecutiveness or adjacency is accomplished by a predicate called adjacent, which has a form (*adjacent* ?*slot_prev* ?*slot* ?*slot_next*), where ?*slot_prev* represents the previously allocated TUs, ?*slot* represents the slot that is being currently allocated, and ?*slot_next* which serve to indicate the next following TU.

Domain Model Actions

The sports planning domain model contains 11 actions, where each action corresponds to one training unit method. It is important to note is that the actions in our domain can be extended, what is more, it is encouraged that the sport domain experts define additional action and adjust the action effects according to their experience. These actions/TUs are as follows:

- **Aerobic** is a name of the action that describes a type of training method that involves activities performed over a longer period of time, such as long-distance running. To ensure that the activity is developing the aerobic system, it is important to monitor heartbeat, which should move between 60% to 90% of an athlete's estimated maximum heart rate. As the name of the action suggest the effect of it increases **aerobic_system** only. There are some constrains concerning aerobic action, which flows from the fact that it typically involves long-distance running and as such, it is highly demanding on the athletes' body. The constraint is that it cannot be executed in a continuous sequence and should not be repeated more than twice a week. Commonly, it is performed only once a week during general preparation, but during the boot camp, it can occur twice a week.

- **Agility** represents in our domain model, a training unit that is focused on an ability to move and change direction and position of the body quickly and effectively. In other words, the TU develops quick reflexes, coordination, balance, speed, and what is more the capability to react on the changing situation correctly. This TU usually includes exercises like shuttle runs, forward-backwards sprints, speed ladder agility drills, etc. Essentially, this action's effects increases **explosiveness** of all body parts but mainly *upper_limbs*. Agility TU can be performed over the whole macro-cycle, but it should not be planned in a continuous sequence and should not combine in sequence with anaerobic and interval action. However, the capacity of this type of action should be mostly spread across general preparation.

- **Anaerobic** is a representation of TU, which mainly develops anaerobic energy system and often improves muscular power, strength and speed in the process [91]. Further, the primary purpose of anaerobic TU is to improve the body ability to remove lactate from muscles and speed up the anaerobic glycolysis to enable for faster production of ATP. The example of exercises involved in this type of TU can be burpees, sprints, high-intensity interval training, rowing, jump rope, etc. The action's effects mainly increase **anaerobic_system** but depending on used exercises the TU can secondarily develop also **explosiveness** and **endurance**. Further, the **endurance** and **explosiveness** increases of body areas' fluents are dependent on employed exercises. The anaerobic training is in its nature demanding, and the body needs time to regenerate, which requires to define a constraint that will allow the same type of action only within two slots apart. Nonetheless, the anaerobic TU is used during the whole macro-cycle that is because boxing/kickboxing is mainly dependent on anaerobic power.

- **Circuit** is action describing a training unit that involves a series of exercises referred to as stations. At each station is performed one activity, which is performed for a certain amount of time followed by a brief break before an athlete moves to another station. A circuit usually consists of 8-10 stations, and each circuit is executed a certain number of times. The circuit can be designed to develop any aspect of fitness abilities, but it is typically designed to develop mainly **anaerobic_system** and **endurance**, but it also secondarily develops **strength** of *upper_limbs, mid_body*, and *lower_limbs*. This TU is also performed during the whole season except for the last two weeks of the competition period. It can be combined with any action but should not be planned in a continuous sequence.

- **Cross** is an action s a training routine that incorporates various training methods to enhance general performance. The purpose of this TU is to take the most effective exercises and adapt them into a high-intensity TU. It combines exercises using load, distance, and speed. The action mainly develops an anaerobic system, strength endurance, and speed. In our model the effects are chosen accordingly and as such the fluents are **anaerobic_system**, **endurance** *upper_limbs*, **endurance** *lower_limbs*, and **endurance** *mid_body*. This action is limited to general and specific period that is defined by its capacity, which is dedicated just for the periods weeks. Further, the action should not be executed in continuous sequence.

- **Fartlek** is a continuous training that combines different levels of speed and terrain or even various activities in order to stress both aerobic and anaerobic system. To put it differently, an athlete is running without stopping but with different intensities, for example, 30 seconds sprint 90 seconds a jog, which is repeated for about 6 to 30 min. The intervals can also include periods of walking, running uphill, downhill and flat running. As this type of training is based on different levels of intensity, it develops cardiovascular fitness, muscular endurance, recovery times and lactate threshold. The action effect fluents are **aerobic_system**, **anaerobic_system**, and **endurance** *lower_limbs*. This method is usually used mostly through general preparation period, which is defined by its capacity for the period weeks. This method should not be combined in sequence with other aerobic actions more than twice in a row.

- **Interval** is a high-intensity TU that is typically involving running exercises that are focused on improving cardiovascular fitness, muscular endurance, speed, recovery times and lactate threshold. The interval method is in our case uses 4 minutes intervals with one minute break. As described above the action improves the anaerobic system, anaerobic system, and explosiveness. As this method is defined as running method the fluents are **anaerobic_system**, **aerobic_system**, and **explosiveness** *lower_limbs*. This action can be used during the whole macro-cycle, nonetheless, it should not be executed more than once a week.

- **MaximumSpeed** is an action that defines a training unit that is typical for a later stage of a training cycle, which takes place during the competition period. The maximum speed TU includes exercises that have to be executed with maximal intensity for a short time. As an example can serve shadow boxing for 10 seconds, followed by a one-minute break. As the TU's name suggests, it is only focused on an athlete speed ability; therefore, the effect increases fluent **explosiveness** mostly focused on *upper_limbs*. However, as a side product, it improves **anaerobic_system**. This action is mainly executed during the competition period, which is defined through the week capacity. Further, this TU is executed along with technical oriented TUs, and often it takes place in a sequence of two units.

- **MaximumStrength** refers to an action that develops maximal strength, which defines the maximal force or energy a muscle can generate with one contraction [27]. Strength training is vital not only for performance but also for injury prevention. The training unit typically consists of activities where an athlete perform force upon an external object (weight lifting), which is executed at higher intensities with lower volume. The action defined in our domain is focused on a specific body part, and the effect of the action is defined accordingly. The action's effects are affecting **strength** fluent of a targeted body part. The primary constraint of the TU is that it cannot be performed in a row as that would decrease the effect of the action and could lead to injury. Further, this action is executed mainly in general preparation period. This constrain is derived from chapters 2.2.1 and 2.2.5.

- **Polymetric** is a method that uses jumps, hops, bounds, and skips. The polymetric TU is utilising a rapid cyclical muscle action referred to as "stretch-shortening cycle" [92]. The example of polymetric exercises can be skipping rope, jumping squats, single-leg hopping and clapping push-ups. The action in our domain model develops mainly **explosiveness**, but also **anaerobic_system**, and **strength**. As this TU is executed with high-intensity with relatively high volume, it is important that it is not executed in continuous sequence and also it is not followed by TUs such as **agilityTU**.

- **StrengthEndurance** action is focused on improving strength, power and muscular endurance. The type of performed strength ability is defined by involved resistance, repetitions and number of sets executed. For strength endurance, TU is typically using external objects such as kettlebells, dumbbells, weights, resistance machines etc. In order to target strength endurance, the involved resistance has to be under maximal load and perform with a higher number of repetitions. For example, an athlete should perform a number of exercises that are performed at 60% for 2-3 sets of 12 to 13 repetitions. The typical break between sets is 2 minutes. The fluents involved in strength endurance action are **endurance** and as a secondary ability increase is **strength**, which both are applied to all body parts. The endurance is mostly performed as other TUs focused at physical abilities planned for the general and specific preparation period, which is also defined throughout the weeks' capacities. The strength endurance should not be scheduled in a continuous sequence and should not be combined with MaxStrength action.

Each action (or exercise) has a limit of how many times it can be scheduled for a single week. Further, most of the action has a designated training period in which they can be executed. The details of the periods has been derived from Physical Abilities chapter 2.2.1 and from ATP chapter 2.2.5. The designation of actions into period is done by numerical constraint, which is represented by a numeric fluent (action-capacity ?action?week). It is important to highlight that for all exercises, except Anaerobic and MaximumSpeed, it is the case that the same type of exercise cannot be scheduled in adjacent slots [3]. To provide better understanding of how the actions are designed, there are provided two distinct examples of actions in PDDL, which can be seen at examples 3.3 and 3.4.

Example 3.3. The example of the aerobic training unit encoded into PDDL action.

```
;This action represent longer runs 15 - 20km
(:action AerobicTU
:parameters (?slot - slot ?slot_prev ?slot_next - slot ?w - week)
:precondition (and
```

```
                    (adjacent ?slot_prev ?slot ?slot_next)
                    (free ?slot)
                    (slot_in_week ?slot ?w)
                    (not (act_allocated aerobic ?slot_prev))
                    (not (act_allocated aerobic ?slot_next))
                    (> (action_capacity aerobic ?w) 0)
               )
:effect       (and
                    (not (free ?slot))
                    (act_allocated aerobic ?slot)
                    (decrease (action_capacity aerobic ?w) 1)
                    (increase (aerobic_system) 0.8)
               )
)
```

Both the examples use parameters ($?slot - slot\ ?slot\_prev$ $?slot\_next - slot\ ?w - week$), which enables us to define preconditions that can restrict the repetition of the same actions where needed. Nonetheless, the action MaximalStrengthTU also includes a parameter $?b - body\_part$. The reason for that is that some of the actions can target only one body part. Assuming the corresponding TU is scheduled to a $?slot$ in a week $?week$, $(free\ ?slot)$, $(slot\_in\_week\ ?slot\ ?week)$ and $(action\_capacity\ ?action\ ?week)$ greater than zero must hold [3].

Example 3.4. The example of the maximal strength training unit encoded into planning action.

```
(:action MaximalStrengthTU
:parameters (?slot - slot ?b - body_part ?slot_prev ?slot_next - slot ?w - week)
:precondition (and
                    (adjacent ?slot_prev ?slot ?slot_next)
                    (free ?slot)
                    (slot_in_week ?slot ?w)
                    (not (act_allocated maximal ?slot_prev))
```

```
                (not (act_allocated maximal ?slot_next))
                (> (action_capacity maximal ?w) 0)
            )
:effect     (and
                (not (free ?slot))
                (act_allocated maximal ?slot)
                (decrease (action_capacity maximal ?w) 1)
                (increase (strength upper_limbs) 1.2)
                (increase (strength lower_limbs) 1.2)
                (increase (strength mid_body) 1)
            )
)
```

To satisfy the non-adjacency constraint, (*adjacent ?slot_prev ?slot ?slot_next*), (*not (action_allocated ?action ?slot_prev*) and (*not (action_allocated ?action ?slot_next*) must hold as well.

Effects of the actions have following parts: i) predicate to mark the slot as not free (*not (free ?slot*)), ii) predicate representing that the action has been allocated (action_allocated ?*action* ?*slot*), iii) when action allocated decreasing the action's week capacity (action_capacity ?*action* ?*week*) by one, iv) and increasing of the corresponding athletes attributes.

The "MaximumSpeedTU" and anaerobic type of TUs are encoded analogously with other actions, although, they do not contain the "non-adjacency constraint", which enables the action to be executed in a row. Furthermore, the "MaximumSpeedTU" action is often required to be scheduled for two adjacent slots leaving the next slot unallocated, which results in no other TU can be scheduled on that slot [3]. The precondition is altered such that ?*slot*, ?slot_prev and ?slot_next has to be in the same week (?*week*) and free. The effects not only increasing the athlete's physical attributes but they also make ?*slot*, ?*slot_prev* and ?*slot_next* "not free" and allocate MaximumSpeed action on ?*slot*, ?*slot_prev*.

Planning Problem File Description

To be able to produce an individual training plan with the help of our domain model, there is a need to compose a problem description for each athlete. The fact that each athlete needs to have a separate problem file ensures the individual approach towards training planning. It worth to notice that the domain model is the same for all athletes of one type of sport. The first step in description of the domain is definition of objects, which are in our case the weeks for the period we plan for and its subsequent number of slots.

The next step is to define the initial state that has to define schedule constraints, which in our case are expressed by the predicate "*adjacent*", *slot_in_week* and predicates "$free$" that represents all slots without allocated action [3]. As the name suggest the "*adjacent*" ensure the continuity of the slots sequence and it is defined as ($adjacent\ slot1\ slot2\ slot3$). Further, the first instance of "*adjacent*" and its first slot parameter has to be a "*dummy_slot*". Similarly, the last "*adjacent*" instance has to have a "*dummy_slot*" as the last parameter such that ($adjacent\ slot_{n-1}\ slot_n\ dummy\_slot$). These dummy slots are required as the "*adjacent*" requires three parameters and the first slot does not have a previous slot $slot_{prev}$ and the last slot does not have the next slot $slot_{next}$. The predicate *slot_in_week* defines the number of slot belonging to a specific week. Therefore, this is one of the predicates throughout is defined the volume of each period and the number of TUs/slots an athlete can dedicate to the training program. The *slot_in_week* predicate includes two parameters which are essentially a specific slot and week to which the slot belongs.

Next, there is a need to include the initial state constraint fluent *action_capacity* that represents the main part of the training volume. Essentially, this fluent expresses the maximum number of particular types of TUs per week, which has a form (= (action_capacity action_name week_number) number_of_actions).

The first iterations of the domain included action effects values in the domain file, which constituted that all athletes respond to the training unit with the same performance improvement. This static approach to the action effects was a good place to start; nonetheless, we understood that this approach is not realistic. Therefore, we resolved this by transforming the effects constants into a numeric fluents that are in the domain file represented as functions, and each effect value is defined in individual problem files. This change enables us to adapt the TUs' improvements for each athlete individually, which makes better and more suitable plans. Examples of effects can be seen in examples 3.3 and 3.4. One of the effect of "*AerobicTU* action is improvement of aerobic system, which is defined as (*increase* (*aerobic_system*) (*aerobic_system_aerobic*)), where (*aerobic_system_aerobic*) is the proposed fluent. Each effect has its value defined in the problem file as (= (effect_fleunt_name) (effect_fluent_value)). It is important to highlight that some of the actions' effects have a body part parameter that corresponds with the action's targeted body part. The example 3.4 shows the effect type with parameter, which has form as follows (*increase* (effect_fluent_name?*b*)(effect_increase_fluent_name ?*b*)).

The last part of the initial state is the specification of an athlete's performance attributes. These attributes are acquired from the performance tests. To find out more on athletes' testing, see athletes' performance testing chapter 2.2.4, and sports performance quantification scheme chapter 3.1.2. Also, further details on performance attributes are provided in chapter 2.2.1 called physical and movement abilities, and also in sports performance encoding chapter 3.1. Once the athletes' attributes gathered, they are encoded in the following form:

Example 3.5. Initial state of an athlete's ability with body part parameter

```
(=(ability_fluent_name body_part) ability_fluent_value)
```

The example 3.5 shows syntax for **strength**, **endurance**, and **explosiveness** abilities' attributes that include body part parameter. The attributes representing **aerobic system** and **anaerobic system** attributes are almost the same except they do not have the body part parameter as they constitute abilities that are applied for the whole body.

Further, there is a need to define goals to be achieved by the automatically generated training plan. The goals express the minimum desired outcomes in terms of the athlete's attributes values that an athlete should meet after the training plan is successfully executed [3]. The goals conditions have a similar form as the initial state with a difference of a "higher than" operator, which is shown in example 3.6. The goal conditions have to be defined for all of the athlete body proprieties.

Example 3.6. The goal condition with body part parameter

```
(>=(ability_fluent_name body_part) ability_fluent_value)
```

Worth to highlight that plans which are leading to higher attribute values are permitted and what is more such plans are desired. Such plans are supported by defining optimisation criteria that are looking for a plan that is utilising one or a multitude of performance attributes. These criteria are defined with the style of kickboxer in mind. For example, if a coach decides that an athlete should incline to be "puncher", then the optimisation criteria will be defined to utilise maximal strength and explosiveness. Such a scenario is shown in the example of 3.7. Also, more details on boxing styles can be found in chapter 3.2.2.

Example 3.7. The optimisation criteria for "puncher" boxing style inclination

```
(:metric maximize (+ (strenght upper_limbs)(explosiveness upper_limbs))
```

After a domain model and problem specification, we can use off-the-shelf planners to produce a plan. The planner resulted plan might not be chronologically ordered in terms of continuity of days. Nonetheless, the plan includes all the required information about what TU should be executed and its scheduled slot. Subsequently, it is straightforward to sort the actions to obtain a chronological training plan.

4. EXPERIMENTS AND EVALUATION

This chapter describes the performed experimental analysis, that aims to show the ability of the designed automated-planning-based method for generating athletes' training plans, and its advantages over hand-made training plans made by an expert. It is important to highlight that the proposed method should be a tool that facilitate rather then substitute coaches' planning efforts. At first, there is an detailed description of case studies that has been undertaken in order to test the feasibility of the sports domain. After the case studies specification, we present and discuss the case studies results. Last but not least, we provide evaluation of our method, which is focused at evaluating the quality of the plans, the process involved, and differences between our and expert approach.

4.1 Case Study Specification

There is a need to describe a number of athletes with different training needs, on which we will demonstrate our training planning approach. Additionally, we provide scenarios, which can occur during a training plan execution. It should be noted that the defined test subjects are made of simulated data collected from various literature; nonetheless, they represent possible real-world scenarios. Finally, we describe the setup that was used for generating the plans, which includes used planner and machine specifications.

4.1.1 Planning Scenarios

Each scenario includes a brief athlete description, a number of weeks for which the plan should be generated, athletes testing results and initial states, and description of desired goals.

The case study is delivered on three athletes that have different performance levels. These athletes performance levels are entry-, intermediate-, and elite-level. It is important to highlight that the scenarios are proposed for athletes who have the same gender and similar body weight, age, and height. Additionally, the defined athletes have same boxing style called outer-boxer, which typically require evenly spread out physical performance. The main reason for this is enabling comparison of generated plans differences in terms of various performance levels.

At first, there is a need to specify the group to which all three athletes belong as it influences an athlete boxing style and testing results, therefore, it has influence on planning outcomes. The group is defined as males of age between 20 to 29 years with a weight range between 80 to 85 kilos, and height between 185 to 190 centimetres.

Our first planning subject is an entry-level athlete. Usually, when a new starters join a club, they do not expect to get to the competition level, and instead, they look for a way to "get into shape". Typically, it is because they cannot see themselves to improve their physical skills to be able to participate in competitions. In these cases, well-planned training units can help them to improve their physical abilities and provide them with courage, and motivation to begin train for a competition. However, entry-level athletes are usually willing to dedicate only up to 3 training units a week, which slows down their potential improvement.

The next subject is an athlete with intermediate-level performance, who already participated in few competitions, but is still in the early stage of his sports carrier. The intermediate-level athletes are usually dedicating to training 3 to 5 training units a week. This enables them to still improve relatively fast compared with entry-level athletes. The last of the subject is an athlete that reached the baseline of elite-level and trains for a specific high-rank competition. In this planning scenario, the athlete is preparing for a national championship. The elite-level type of athlete is typically committed to 7 to 10 training units a week.

We defined three different scenarios for each athlete:

- a plan for nine weeks with 45 slots that serve for comparison between performance groups
- a plan for nine weeks with included boot camp;
- a full 12-week general preparation plan.

Boot camps, as described in section 3.2.1, are weeks of subsequently practising for maximal strength, followed by breaks to recover.

4.1.2 Planning Problem Files Specification

In this section, we define athletes' testing results, initial states, goal states, and other changes to the problem file according to the planning scenarios. One of these changes is defining the training volume for each athlete that is in the problem file represented by the number of *slots*, predicate *slot_in_week*, and defining the capacity for individual actions. Another, differences between the planning files is the actions' effects that are defined with help of fluents in the problem file. This is done to enable more flexible planning approach that incorporates the changes in the athletes improvement according their performance level.

Testing Results and Initial States

The first step in the planning process is to conduct an athletes' testing that is used for defining individual athlete initial state. As already mentioned, we simulate the testing data from a number of literature sources. The athletes' test battery results are presented in table 4.1. Further, the table is containing the estimation of the best and worst results for each test as it is needed for the quantification scheme formula that transforms the results into physical attributes. To find out more about the quantification scheme see chapter 3.1.2. Further, the best results of each test can be seen in the b_i column and the worst in the column w_i. The athletes' initial state physical attributes are presented in table 4.2.

Table 4.1.
Athletes Performance Test Results. b_i and w_i indicate representations of the best and the worst measured results, respectively.

test name	**entry-**	**inter.-**	**elite-**	w_i	b_i
aerobic system					
cooper's test (m)	2100	2400	2600	1600	2850 [93]
anaerobic system					
burpees in 60sec. (rep)	35	53	66	15	83 [94]
endurance					
push-ups max rep.	32	47	58	18	67 [95]
sit-ups max rep.	36	54	69	25	82 [96]
squats max rep.	35	42	52	20	65 [95]
explosiveness					
standing long jump (m)	2.2	2.65	3.2	1.7	3.75 [97]
sit-ups 60 sec. (rep)	29	35	42	25	47 [98]
medicine ball throw (m)	3.2	4.4	4.9	2.5	5.9 [99]
strength					
banchpress max (kg)	55	78	90	30	120 [100]
abdominal crunch max (kg)	20	37.5	60	0	79 [101]
squat max (kg)	45	80	110	25	140 [100]

Taking a closer look at table 4.2, it is easy to see that, even though the testing results are the absolute values of the athletes' performance, they do not give a clear understanding of how good the athletes' abilities are compared with each other. On the other hand, the transformed values in table 4.2 give a straight forward representation of each ability performance level. As an example can serve aerobic system attribute of entry-level athlete, who reached in the cooper's test 2100 meters, which transfers into aerobic system attribute with 40% of the best measured performance in the test group. In a sense, the quantification scheme helps in synthesising the differences in performance of the different levels of athletes.

Table 4.2.
Testing results transformed into abilities fluents required for the initial state

Ability Name	**entry-**	**mid-**	**top-**
aerobic_system	40.00	64.00	80.00
anaerobic_system	29.41	55.88	75.00
strength upper_limbs	27.17	52.17	65.22
strength mid_body	25.32	47.47	75.95
strength lower_limbs	17.39	47.83	75.91
endurance upper_limbs	28.57	59.18	81.63
endurance mid_body	19.30	50.88	77.19
endurance lower_limbs	33.33	48.89	71.11
explosiveness upper_limbs	24.39	46.34	73.17
explosiveness mid_body	18.18	45.45	77.27
explosiveness lower_limbs	20.59	55.88	70.59

After introducing athletes' testing results and their quantification, that can be used to define the initial state of a planning problem, there is a need to define goal states and optimisation criteria.

Athletes' Goal States

The goal states represent desired improvement of each athlete physical abilities, and the corresponding values for all three scenarios can be found in tables 4.3, 4.4, and 4.5. There is need to highlight that the planning goals have to be realistic, otherwise a plan generation may fail to produce any plan as it may not exist. We defined such goals for each athlete and provide maximisation criteria that ensure that the plan length is fully used and required physical abilities are utilised.

The entry-level athlete and intermediate-level athletes desired improvements are relatively evenly spread out. The reason behind this is that the athletes need to have a good base line performance in order to be able to closely focus at some of

Table 4.3.
Goal state fluents defined period lasting 9 weeks and 45 slots. The abilities defined in maximise criteria are marked by *

Ability Name	**entry-**	**inter.-**	**elite-**
aerobic_system	42*	70*	83
anaerobic_system	33 *	65*	78
strength upper_limbs	30	56	71*
strength mid_body	26	52	78
strength lower_limbs	22	52	75
endurance upper_limbs	30	63	83
endurance mid_body	25	55	79
endurance lower_limbs	35	53	73
explosiveness upper_limbs	30	54	75*
explosiveness mid_body	26	51	79
explosiveness lower_limbs	22	58	74

the abilities in which they perform the best. On the other hand, elite-level athletes goals are more specific in terms of focusing at particular abilities that give them the competitive advantage as they have the experience and appropriate level of physical performance.

Finally, we define the optimisation criteria for each athlete. It has been decided that entry- and intermediate- athletes have same maximisation function in order to preserve the main objectives of the case study that are to demonstrate the planning approach but also to compare the plans in terms of athletes' performance levels. The maximisation criteria for these athletes are focused at aerobic and anaerobic system and are define as (: *metric maximize* (+ (*anaerobic_system*)(*aerobic_system*)).

Although, to provide additional example of how the optimisation criteria works the elite athlete has maximisation metrics chosen according to abilities on which the plan is focused the most. These criteria for elite athlete are defined as follows (: *metric maximize* (+ (*strength upper_limbs*)(*explosiveness upper_limbs*)). As it is possible to see all of the athletes maximise metrics are defined as a sum of two abilities. Note that it is possible to define metrics that would include additional

Table 4.4.
Goal state fluents defined for 9 week with boot camp. The abilities defined in maximise criteria are marked by *

Ability Name	**entry-**	**inter.-**	**elite-**
aerobic_system	45*	74*	83
anaerobic_system	37 *	67*	82
strength upper_limbs	35	57	73*
strength mid_body	30	53	78
strength lower_limbs	27	55	75
endurance upper_limbs	34	66	85
endurance mid_body	25	57	80
endurance lower_limbs	35	55	78
explosiveness upper_limbs	30	55	78*
explosiveness mid_body	25	55	80
explosiveness lower_limbs	27	60	74

abilities. However, in most cases, it is sensible to define maximise criteria up to three abilities. In the case of the entry and intermediate athlete is at energy systems as they are the base for further development of other abilities. In contrast, the elite athlete can focus at any abilities on which they agree upon with a coach, and in this case, it is strength and explosiveness of the upper limbs to provide the athlete with ability to have greater force punches.

The next chapter presents plans that have been generated by using the introduced domain model.

4.1.3 Machine and Planner Specification

All the experiments were run on a machine equipped with an i5-6200U 2.3GHz 64-bit CPU, 8GB RAM, and Ubuntu 18.04 operating system. We considered a cutoff time of 30 CPU-time minutes. However, it is worth reminding that in this application domain, the time needed to generate a training plan is not the critical aspect: human experts can take up to days to generate a single one.

Table 4.5.
Goal state fluents defined for full general preparation period made of 12 weeks. The abilities defined in maximise criteria are marked by *

Ability Name	entry-	inter.-	elite-
aerobic_system	45*	74*	83
anaerobic_system	34*	67*	76
strength upper_limbs	32	57	69*
strength mid_body	27	53	78
strength lower_limbs	23	55	75
endurance upper_limbs	32	66	83
endurance mid_body	25	57	79
endurance lower_limbs	35	55	73
explosiveness upper_limbs	27	55	77*
explosiveness mid_body	22	55	81
explosiveness lower_limbs	24	60	74

As a planner, we selected to use the well-known LPG planner [102] due to its widespread use in applications, and to its ability to generate solutions quickly. In particular, given the stochasticity of the search approach exploited by LPG, we fixed its seed and we selected the best plan generated out of 10.

4.2 Experimental Results

In this section, we present experimental results, which are consistent with nine generated plans that have been conducted according to planning cases described in chapter 4.1. In short, these cases are based on three athletes that have different performance levels, and each of them has three different planning scenarios. These scenarios are nine weeks with 45 slots (training units), nine weeks including boot camp, and a full 12 weeks general period without boot camp.

An example of raw outputted plan data can be found in figure 4.1 and the full example can be seen in appendix C.

```
0:    (ANAEROBICTU SLOT43 LOWER_LIMBS SLOT42 SLOT44 W9) [1]
0:    (AGILITYTU SLOT41 SLOT40 SLOT42 W9) [1]
0:    (MAXIMALSTRENGTHTU SLOT45 LOWER_LIMBS SLOT44 DUMMY_SLOT W9) [1]
0:    (AEROBICTU SLOT16 SLOT15 SLOT17 W4) [1]
```

Fig. 4.1. Excerpt of a plan generated for the entry-level athlete for 9 weeks with 45 slots scenario.

The output generated by the planner is then modified by a dedicated script in order to sort the actions to be performed. An example of the script output can be found in figure 4.2. The full sorted plan for entry athlete is provided in the appendix D and rest of the sorted plans can be found on the attached disc at each plan version in the files called *SortedActions.txt*.

```
1  T_Day:1 STRENGHTENDURANCETU SLOT1 UPPER_LIMBS DUMMY_SLOT SLOT2 W1
2  T_Day:3 INTERVALTU SLOT3 UPPER_LIMBS SLOT2 SLOT4 W1
3  T_Day:5 FARTLEKTU SLOT5 LOWER_LIMBS SLOT4 SLOT6 W1
4  T_Day:6 STRENGHTENDURANCETU SLOT6 UPPER_LIMBS SLOT5 SLOT7 W2
```

Fig. 4.2. Example of plan sorted by the script.

The sorted plans are then presented in a more visual form, to foster validation and analysis by domain experts. An example can be seen in figure 4.3. We provide three other plans in the appendix F, which are: a plan for entry athlete with nine weeks consistent of 45 slots, a plan for an intermediate athlete for nine weeks including boot camp and a plan for an elite athlete for 12 weeks.

We provide in appendix B three tables, which give an overview at the produced plans in terms of a type and a number of generated actions. Table B.1 show the number of actions of all three scenarios for entry athlete. Similarly, table B.2 and B.3 shows results of the intermediate and elite athlete, respectively. These results show the different proprieties of the plans, which can be seen in their differences and similarities.

	Week 1	Week 2	Week 3
Monday	INTERVALTU MID_BODY	POLYMETRICSTU LOWER_LIMBS	STRENGHTENDURANCETU LOWER_LIMBS
Tuesday	FARTLEKTU UPPER_LIMBS	FARTLEKTU LOWER_LIMBS	INTERVALTU LOWER_LIMBS
Wednesday	POLYMETRICSTU LOWER_LIMBS	STRENGHTENDURANCETU LOWER_LIMBS	AEROBICTU
Thursday	FARTLEKTU MID_BODY	CIRCUITTU UPPER_LIMBS	FARTLEKTU LOWER_LIMBS
Friday	STRENGHTENDURANCETU MID_BODY	AEROBICTU	CIRCUITTU UPPER_LIMBS

	Week 4	Week 5	Week 6
Monday	POLYMETRICSTU MID_BODY	INTERVALTU MID_BODY	CIRCUITTU UPPER_LIMBS
Tuesday	AEROBICTU	CIRCUITTU MID_BODY	INTERVALTU UPPER_LIMBS
Wednesday	CIRCUITTU UPPER_LIMBS	STRENGHTENDURANCETU MID_BODY	POLYMETRICSTU MID_BODY
Thursday	AEROBICTU	MAXIMALSTRENGTHTU MID_BODY	STRENGHTENDURANCETU UPPER_LIMBS
Friday	FARTLEKTU UPPER_LIMBS	POLYMETRICSTU LOWER_LIMBS	FARTLEKTU MID_BODY

	Week 7	Week 8	Week 9
Monday	POLYMETRICSTU LOWER_LIMBS	CIRCUITTU LOWER_LIMBS	CIRCUITTU UPPER_LIMBS
Tuesday	INTERVALTU UPPER_LIMBS	POLYMETRICSTU MID_BODY	POLYMETRICSTU MID_BODY
Wednesday	FARTLEKTU MID_BODY	MAXIMALSTRENGTHTU LOWER_LIMBS	INTERVALTU UPPER_LIMBS
Thursday	MAXIMALSTRENGTHTU UPPER_LIMBS	INTERVALTU LOWER_LIMBS	FARTLEKTU LOWER_LIMBS
Friday	INTERVALTU UPPER_LIMBS	FARTLEKTU LOWER_LIMBS	ANAEROBICTU UPPER_LIMBS

Fig. 4.3. Intermediate athlete plan for 9 weeks made of 45 slots.

Let us take the first action called *AerobicTU* that is focused on developing the aerobic system. You can see in tables B.1,B.2, and B.3 that this action is repeated more than any other training unit across all of the plans. The reason for this is that improving aerobic energy system provides the means to perform throughout the whole season. Further, the number of the *AerobicTU* actions are higher at the planning scenarios that include boot camp. The higher volume of these training units is a reflection of the fact that boot camps increase the number of slots and are usually focused on progressing the aerobic system.

Another high usage action is $FartlekTU$. Even though it has a body part property, it is mainly focused on both energy systems and strength endurance of lower limbs. This action is desirable, especially for intermediate and elite athletes as their improvement throughout the whole general period should be aimed at anaerobic and secondarily aerobic systems. Again, $FartlekTU$ improves the anaerobic system that is a crucial part of physical performance in kickboxing. Same as *AerobicTU*, $FartlekTU$ has a higher number of instances across all plans but with the difference of targeting specific body part. For example, plans for entry athlete favour $FartlekTU$ with property $UPPER\_LIMBS$ as the initial athlete state for upper limbs strength endurance is lower than for other body parts. On the other hand, the intermediate athlete has a lower initial state of lower limbs strength endurance; therefore, there is a higher number of the $FartlekTU$ actions with property $LOWER\_LIMBS$.

Another action worth to mention is $CircuitTU$, which also has an elevated amount of instances for intermediate and elite athletes plans for all three body parts. The reason behind this is that this training unit is more efficient when executed by a more advanced athlete. Nonetheless, some of the $CircuitTU$ actions need to be also incorporated in entry-level training plans. In our case, the $CircuitTU$ is incorporated for entry athlete, especially with the property mid-body as his initial state for strength endurance and explosive strength is noticeably lower than other abilities. The reason for focusing on lower-performing abilities is derived from the style of boxing. The style for all our athletes was defined as a complex technical boxer that requires to have relatively evenly spread out physical performance.

The action $IntervalTU$ can be seen as interesting as it provides a good insight into the main training demands on athletes. For example, it is possible to observe that the number of actions is elevated in the plans that last for the full 12 week period. The reason for it is that the focus towards the end of the general period is changing from an aerobic type of actions towards anaerobic type. Other than that, the $IntervalTU$ is relatively evenly spread across the whole period for all plans.

It is possible to observe that all of the planning scenarios have a relatively similar amount of $MaximalStrengthTU$, which is spread across third to sixth and ninth to the twelfth week. This is done according Aiba based abstract annual training plan that can be found in appendix A [39]. However, the elite athlete has a considerably higher volume of these actions as his goals and optimisation criteria was set to maximise maximal strength and explosiveness of upper limbs.

The Aiba annual training plan also shows that the explosiveness needs to be progressed through all season. It also shows that the anaerobic system development should start form forth week till the end of the season. It is facilitated mainly by three types of actions, which are $PolymetricsTU$, $AnaerobicTU$, and $AgilityTU$.

Let's take for example the *PolymetricsTU*, which has high amount of instances across all plans. In case of entry athlete plans these actions are mostly focused on lower limbs. Nonetheless, the reason for a higher number of this type of action in entry athlete plans is that the anaerobic system and explosiveness are defined with high goals and *PolymetricsTU* targets both of these abilities. In the case of the intermediate athlete, it is not only lower limbs but also mid-body, which has a higher number of *PolymetricTU*. There is the main reason the fact that the athlete has the initial state of explosiveness and strength of lower limbs and mid-body quite low and their goals are relatively high. It was done to reach a similar performance of other abilities. In the case of the elite athlete, the *PolymetricsTU* is focused mainly at upper limbs, which is a result of the optimisation criteria, which also defined to maximise explosiveness of upper limbs.

Further, after collecting all input data, the generation of each plan took a maximum of 17.58 seconds, and in most cases, a plan was generated in less than one second.

All things considered, there is no doubt about the fact that with a higher number of slots, an athlete can reach better outcomes from the plan execution. Therefore, the full twelve weeks period and the planning scenarios, including boot camps, provides higher projected physical performance.

4.3 Validation

Here, we provide a discussion on the planning process proposed by this research, the planning approach and its validity, and the acceptance evaluation by an expert coach. Additionally, we aim to show that our planning approach is a viable option for coaches planning efforts.

There is a need to mention that the originally proposed evaluation method was a comparison of automatically generated plans with manually produced plans throughout a clinical trial. The clinical trial would have been composed of 40 athletes split into two groups, where one group would use the plans generated by our domain, and the other would use manually made plans. The subject groups would follow the plans for a year, and they would be evaluated multiple times throughout the year and at the end of the trial period. The reached performance would be compared and evaluated against each other. Such a study would provide a great insight into the effectiveness, usability, and its ability to impact the training planning. However, the complexity of the clinical trial and its demands on time, financial and also human resources are far beyond the scope of this PhD study. Therefore, we decided to make a qualitative comparison between our plans and plans made manually by an expert. Further, there have been conducted an interview with the Czech national coach for kickboxing who evaluated our planning approach and quality of our produced plans. He provided us with his manually produced plans that we use as a baseline for our evaluation, and as a ground for discussing.

The expert provided three plans specifically made for the general preparation period that run for nine weeks. These plans were used in by the coach in 2008, 2015, and 2016. These plans can be found in appendix E. As described in previous sections, in our experimental analysis we specified nine planning problems that are made for different scenarios. Nonetheless, three of these scenarios reflect the setting of the coach's plans and, additionally, considered different athletes' performance, i.e., entry-, intermediate-, and elite-level. The reason for reflecting different performance athletes flows from the fact that we are aiming to generate individualised plans, while the coach's plans were created for a group of athletes [3].

The figures E.1 and E.2 provide the full expert training plan. Each plan took several hours to be crafted, usually between 3 and 5. Furthermore, it is easy to observe that the plan is mostly an abstract overview of the general preparation period, which includes a mixture of technical and physical training. The plan is made of six different types of training units. Additionally, expert's plans incorporate a location where the training units take place. For example, let us observe the first two training days, which indicates that the Monday training unit is executed at the running track and the Tuesday training unit takes place in the clubs gym. Of course the location information is again very general, and could be easily incorporated in automatically generated plans.

Another part of the plan worth to mention is the boot camp that has dedicated days' slots, but none of the training units is allocated. The reason behind not allocating the training units is that the coach creates a boot camp plan a few days prior. Again, this is done because planning is an extremely demanding and time-consuming process, and often there are many changes in the dates; therefore, it is challenging for a human coach to define boot camp in advance.

The main difference between expert's and our plans is that the expert plans define mostly abstract training units that indicate the kind of training, where our plans define specifically the training method that will be used. As an example, abstract training unit can serve "Technique and Running", which defines that some of the training will be made of technical practice and another part by some kind of running practice. Our plans define explicitly what type of training unit will be executed, which can be demonstrated on the training units $IntervalTU$ that defines running in short intervals such as sprints, or $FartlekTU$ that defines longer interval running. In that, it is easy to notice that the higher level of detail of the automatically generated plans can help having a more well-defined training for the athlete, and outcomes can be more precisely assessed.

Notably, the expert's plans also include some specific training units such as ten kilometres run, half marathon, and interval running. These specific training units are executed up to twice per plan. The expert explained that these specific training units are in the plan mainly to mentally prepare the group of athletes for these demanding practices. Nonetheless, these specific units can also be executed in the planned abstract unit called "Technique and Running". This seems to indicate that the training plan itself serves mainly as an organisational tool used by the coach to manage his team. In a sense, the team of athletes which is provided with such training plan is still in the need of a coach to be guided, as general activities need to be spelled out. As said before the plan is made for a group that consists of various performance level athletes. This would suggest that all there is no individual approach to the planning. However, the interview we had with the coach revealed that these plans are used as a bone structure for all team, and the elite level athletes have additional training units that are done ad-hoc from the expert experience. Such additional units seem to be decided more following a “rule of thumbs” than a principled decision process. The analysis of the manually generated training plans, and the discussion we had with the expert coach, indicates that the proposed approach for generating personalised training plans is extremely attractive for the domain expert. It has the potential to reduce the burden on the human expert to create plans, and detailed personalised plans can be very quickly generated.

We then presented the coach with our planning approach and the generated plans, for which he provided us with feedback. At first, the expert was provided with an explanation of the ground on which our domain was built on. After, we followed with a demonstration of steps that are involved in our automatic training plan generation. The research idea and the process of planning have been well understood from the side of the coach. This aspect plays a significant role: if domain experts can understand how the proposed approach works, they are more likely to use it in practice [103]. Further, the expert provided positive comments on our planning process in terms of the assessment of athletes’ performance and clarity of the acquiring of the physical attributes.

As a next step, we provided the expert with our planning scenarios and accordingly produced plans. At first, we presented the entry-level plan made for nine weeks that includes 45 slots from which 27 have allocated training unit. The expert confirmed that the plan is sound and could be executed by a lower-performing athlete. Further, in his opinion, he would recommend such a plan to an athlete who has low performance but has some training experience as the plan could be too demanding for a complete beginner. This flows from the fact that we set our domain according to the Aiba annual training plan that is made initially for an elite athlete. However, our planning domain can be easily set to generate plans with lower demands.

Then, we presented the intermediate and elite athletes' plans, which also consider the need for technical training units. As our research deals with the physical preparation, we added $notfree$ slots that indicate slot for technical training or break from training that serves for athlete's regeneration. These plans have been validated and confirmed as sound with minor remarks. For example, the expert expressed concerns that the elite athlete plan has in two subsequent weeks, two training units in a row that both target upper limbs, which would be possibly too hard to follow. This aspect can be overcome by adding a new constraint that would limit the generation of training units with the same body part attribute. In fact, this can be an additional set of sport-specific constraints that can be used to extend the basic blue-print domain model.

We then discussed and analysed the plans produced with boot camps. The plans, in general, were affirmed by the expert as sound. However, the expert had remarked that boot camps are usually run with a group of athletes with a different performance group, and it would not be sensible to make each athlete have a completely different itinerary. In other words, it is not possible to have athletes with different training plans as the training units would clash from the organisational point of view. This is indeed a very sensible observation. From the point of view of our model, the alternative would be to define common training slots and individual training slots, which would provide a more realistic option. Our domain model allows for such an option as we can define slots as $notfree$ that would indicate the common training unit. Further, the expert observed that the training units are focused purely at physical abilities, and from his experience, there is a need for a technical type of training units. It is currently unclear whether this observation is specific of kickboxing, or is general among competitive sports. However, this can ever be specified by additional sport-specific constraints, or by allocating $notfree$ slot that would be used for the technical training unit. After discussing possible setting options with the domain expert, we come to the conclusion that the domain and problem models can be easily set to generate boot camp plans that would suit the expert needs.

The expert also highlighted the time-saving aspect of our approach, so he can save a lot of time resources (hours per athlete) that he had to spend preparing training plans.

Another interesting aspect that the domain expert appreciated of the proposed approach is its flexibility. The generated training plans also provide information how athletes' attributes are expected to develop in time. If, for example, we observe that after two weeks of training, an athlete's actual performance considerably differs from the expected one, we can specify a new planning problem (from the third week onward and considering the actual athlete's performance) and generate a new training plan. In other words, we can easily adapt plans according to observed athletes' performance even during the training period, and implement a planning-monitoring-replanning approach. The planning-monitoring-replanning approach would require several physical testing rounds during the execution of the plan, which would be compared with the plan's expected performance. If the performance would not fit within specified boundaries, a re-planning would take place.

There is a need to highlight that usually in practice the plan is set at the beginning of the season and blindly followed throughout. The reason behind this is that the coaches do not have specific goals and metrics, as they typically train their athletes to reach the highest possible performance without explicit physical performance goal in mind. Our approach enables for a paradigm shift from unspecific physical goals towards the ability to have complete control in terms of physical performance outcomes. This shift comes from our approach need for explicitly chosen goals.

Interestingly, the domain expert expressed concerns about managing a larger group of athletes with individual training plans because each athlete might do a different exercise at a time. This is a very compelling point. On the one hand, highly personalised training plans may allow athletes to more effectively reach their best performance. On the other hand, this would indeed be challenging for coaches that have to follow a large group that is performing very different tasks in parallel. For the cases in which the coach prefers to have uniform training plans for a group of athletes, it would be enough to use our approach for creating a plan for a uniform group of athletes (e.g. entry-, mid- and top-level). In the future, we plan to integrate coach and space/facility constraints into our method [3].

Summarising, the generated plans have been deemed to be sound and valuable by the Czech national coach for kickboxing. The automatically generated plans are more detailed than manually-generated ones, and can be created for a specific individual. The proposed approach can therefore be a valuable tool for coaches, that can quickly generate high-quality plans; the use of the plans can also lead to a paradigm shift in the field, where training can be more goal-driven by measuring the improvement achieved by athletes. Further, the coach expressed interest in trying our planning approach in practice on his athletes.

5. DISCUSSION

This chapter mainly focuses on motivating the design choices and alternatives approaches that were considered when defining the sports quantification scheme and the reasoning for choosing the 2.1 version of the PDDL language. Section 5.3 discusses the generalising capabilities of the proposed approach to be used for generating training plans for other sports.

5.1 Sport Performance Quantification Scheme

After completion of definition of athletes abilities and dividing the athlete body into separate body parts, there was a need to identify the performance state of each body part ability. It is essential to highlight that without value-based performance, it would not be possible to create a computer-based solution, such as automatically-generated plans. At first, we found several tests that would identify an athlete's performance for the individual abilities of each body part. This provided us with a range of metrics-units, which are used within the tests. Initially, we considered using original test metrics for athlete's abilities, such as measurement in a number of repetitions for the push-up test, meters for distance jumps, kilos for weight lifting, etc. Nonetheless, this option has not been feasible for a number of reasons:

- test values do not provide a clear understanding of athletes' performance, as they do not test a specific part of the body, but gives a kind of summary of a mix of aspects.
- the results of such tests are provided in a wide range of metrics and measures, that cannot be directly related to general performance of an athlete or to part of the body.

- the lack of uniform metrics, and the complexity of linking specific test results and overall performance of a given part of the body makes it impossible to describe a suitable goal condition.

Therefore, a literature survey was conducted to find an existing framework that would enable us to transform an athlete's testing results in more suitable values to be used for the sake of automated planning.

The literature search was not conducted only to find the framework, which would allow us to convert the results into more sensible values for the planning domain, but also to provide us with a better understanding of the performance gap between athletes. When using multiple tests for identifying the performance of one ability of a single body part, the differences between test units can make it extremely difficult to compare them. An additional reason for converting results into a standardised scale is to be able to use a multitude of tests, which would give us more precise performance states and combine them in one performance value.

However, after an extensive literature search, we have not found any existing framework, which we could use for the purpose of our research. The creation of conversion of testing results into a unified scale become an essential need without which our proposed model could not proceed. For that reason, the researcher of this study started investigating possible options for developing a unified scheme for athletes' performance testing results. At first, a performance test battery has been chosen to identify a variety of units used for each ability performance test. After collecting all necessary tests for identification athlete performance state, it was essential to identify boundaries for our scale. The range boundaries of the Sport Performance Quantification Scheme (SPQS) initial version were the best and lowest results observed for each test. These boundaries enabled us to identify the range of the scale, which is simply the best result subtracted by the lowest result. While we had the boundaries and the range, there was a need to find the best possible scale on which we would place our results.

The first design of the scale was to use range from -100 to 100, where 100 represented the best result and 0 represented the lowest result. According to this scale, the athletes who would result under the lowest result would have a minus value, which would impact their overall performance. The reason for this was to require athletes balanced physical performance. The last step was to create a calculation, which would place the test result on the proposed scale and return the appropriate value. Therefore, the following calculation was formed:

First version of SPQS calculation

$$x = \frac{r - l}{b - l} 100 \tag{5.1}$$

In the formed equation 5.1, the symbol x expresses the performance ability value, which can range from -100 to maximum 100. To place the result r on the scale it is subtracted by the lowest l and divided by the range, which is expressed as subtraction of the best result b by the lowest result l. It is important to highlight that the values b and l are the best and the lowest result, respectively, of the tested group. The final value is multiplied by 100 that supplies us with percentile performance comparing the best and lowest athletes' performances.

After we mocked-up athlete's test result data, we transformed them into the scale values and examined them, which can be seen in tables 5.1 and 5.2.

The trial of the first version of SPQS provided us with the understanding that the percentile scale ranging from 0 to 100 provides us insight into athlete's performance level in accordance to the best and lowest result within the tested group. To put it differently, it can be seen that the calculation give us relatively favourable results.

Even though we already had a stepping stone to the calculation of value for our research purposes, we recognised two issues with our calculation. These issues were the chosen range of $(-100, 100)$ and boundaries that are in the form of test's results extremes.

Table 5.1.
Mocked-up push-up test data for SPQS development

	Result	**Calculated Value (%)**
Best (b)	67	
Lowest (l)	18	
Result 1	5	-26.5
Result 2	32	28.6
Result 3	47	59.2
Result 4	58	81.6

Table 5.2.
Mocked-up long-distance jump test data for SPQS development

	Result	**Calculated Value (%)**
Best (b)	3.75	
Lowest (l)	1.7	
Result 1	1.1	-29.2
Result 2	2.2	24.4
Result 3	2.65	46.3
Result 4	3.2	73.2

The reason why the range is an issue is the negative part of the scale as it provides us with inadequate punishment for the overall performance. Further, it does not add any advantage over using a less complex scale. This was a reason why we decided to drop the $(-100, 0)$ and use only the scale ranging from 0 to 100. The results that score below the lowest result are awarded 0.

Additionally, the scale boundaries of the best and lowest were problematic. According to the current calculation, if there is an outstanding performer, it would radically decrease performance values of even top performance athletes. In other words, when more extreme test boundaries are involved the test results values of other results become unreliable as they project that even elite athletes with excellent performance have poor results. To eliminate such a case, we decided to use approximate best an approximate lowest test result as boundaries.

The final version of the sports performance quantification scheme calculation can be found in the chapter 3.1.2. It also includes the indication that the final result of a body part's ability performance can be summary of various test.

5.2 PDDL Choice

To be able to deliver the domain model, there was a need to adopt a planning language that would satisfy the needs of the identified sports planning problem. As the sports domain was identified by this research as a numerical planning problem, the clear option was to use PDDL.

PDDL was chosen as it is a well-known language within the automated planning community. The motivation to develop PDDL comes from an attempt to standardise automated planning languages, and as such was, it is crafted in a way which enables us to compare planning systems and approaches directly. This ability provided faster progress in the field. This fostered the fact that PDDL is supported by many domain-independent planners, which aided in more argument to chose this language for our research. Another reason for the choice is the large number of literature that was published on behalf of the PDDL. For example, most of the IPC papers are using this language, and as such, they provided us with great literature resources for instance the language documentation and planning domain examples.

Additionally, there are many planners that support this language. For our purposes, we decided to use the well-known LPG planner [102] due to its widespread use in applications, and to its ability to generate solutions quickly. As the purpose of the research was to provide a proof of concept that would determine the usability of automated planning in sports planning there have not been needed to employ multiple planners, which would determine what planner is the most performant for the given domain.

Besides multiple versions of PDDL we also considered other languages, which are used by the planning community, such as NDDL, and ANML. However, it was crucially important to choose a language that would provide the right amount of expressivity that was required, without dramatically reducing the number of planners have to reason on the encoded models. Therefore, the main reason for choosing PDDL version 2.1 is that it satisfies all domain definition and planning requirements needed. Further, the decision not to choose the higher version or other language is based on the fact that even though it allows for more extensive functionality, it also increases the complexity even without adding any additional features to the domain. Consequently, to select a higher version or different language with higher expressive power would be irrational and would result in lower performance. However, there is an intention to improve the domain functionality by involving dynamic effects; in such a case a higher version of PDDL will be employed.

5.3 Sports Domain Model Reusability

As a whole, the overall proposed architecture can be re-used for generating training plans for different sports. In this section we focus on the generalizability of the encoded domain and problem models, that represent the key part of the framework.

As the model was created for the purpose of verifying the proof of concept that automated planning is applicable for sports planning, there was a need to select an individual sport that would be the stepping stone. According to the author's experience in martial arts, the selected sport became kickboxing, specifically the general preparation of the annual training cycle. The reason to choose the general preparation was that the majority of the defined training units within the planning domain could be in later stage reused in other sports with only minor adjustments that would reflect the specific need of the sport to which the domain would be applied.

The construction of the domain model is based on the individualisation of the training process, where a personalised plan made of training units is generated for an athlete. As a result, individual sports involving physical abilities, such as athletics sports, tennis, CrossFit, gymnastics, etc. can straightforwardly benefit from the proposed approach. Limited modifications would need to be made in order to cover a slightly different range of training units.

Even though the domain is not build to support team sports training planning, often athletes within teams have individual training plans for physical training. For example, football, ice-hockey, and volleyball players have individuals training plans to improve their physical abilities. Individual training plans for team players are usually used within top teams with sufficient resources, which enables them to provide such plans. Our approach could enable us to deliver training plans not only for those teams but especially for teams that do not have access to such resources.

It was stated that the domain model had been tailored to the kickboxing. However, emphasise was given to develop a model as generic as possible. Therefore, the sports knowledge has been encoded in a way to enable for its reuse to an extent. For instance, the planning actions that describe the training units can be reused into other sports, although some of the conditions may need to be extended. Let us take, for example, weight-lifting training. In our model, the MaximalStrengthTUs are not allowed to be executed in sequence, wherein weight-lifting training such sequence would be desirable. Further, the condition for weight lifting would need to change for not allowing two training units with the same body-part attribute. Another important concept in our model is *action_capacity*, which defines the number of allowed training units of the same time in a specific week of the training cycle. The *action_capacity* values in our model are specific for the annual training planning for athletes from boxing and kickboxing. To adapt this concept for other sports, the values have to be changed according to the particular sport needs.

In any sport, there are different athlete performance groups and athletes with different body properties. These differences and also time resources availability influences the number of training units slots within the training plan. The number of training slots should be agreed upon by the coach and the athlete prior to the planning. Further, each sport domain expert must choose sensible actions effects. In the current state of the domain, defining action effects is a requirement for adaptation of the domain for any other sport. However, there is an intention to adapt dynamic effects that would eliminate this need in the next development iteration of our domain.

In conclusion, taking an AI planning perspective, most of the domain model constructs are generic except for some action conditions and actual values of attributes. Therefore, large part of the model can be re-used or easily adapted for different sports. Similarly, the structure of problem models would remain the same among different sports, but initial conditions and goals will need to be modified. However, adaptation for other sports needs fine-tuning of the effect that each training unit can have on different level of athletes, and would require an expert in the field to guarantee accurate models.

6. CONCLUSION AND FUTURE WORK

In this thesis, we have exploited automated planning in real-world scenario concerning generating plans for athletes physical preparation. In other words, we contributed to the interdisciplinary application of automated planning for sports training planning. We focused on obtaining sports science and automated planning knowledge and transforming it into a sports domain planning model defined in PDDL. This knowledge has been provided by extensive background research that can be found in chapters 2.1 and 2.2. The obtained knowledge furnished us with not only the fundamental knowledge of sports training, but what is more provided us with sport planning requirements and physical performance attributes that are the foundation for our planning approach.

On the ground of the research done, we have designed and developed a new technique for quantifying athletes' physical abilities, that is an essential part of our planning approach. This technique enables us to transform athletes testing results in sensible values that represent an athlete physical performance. Some sort of "features" of the athlete condition. These values can then be used to describe an athlete's initial state in a planning problem, and can be used to define a goal state that the athlete needs to reach via appropriate training. Therefore, the quantification of physical abilities allows us to accurately describe training aims, and to determine a plan success or failure.

In order to evaluate the validity of the proposed approach, we conducted an experimental demonstration on simulated athletes data that have been collected from testing results from multiple studies. The experiments provided us with an understanding of our approach advantages and limitations. The demonstration has been composed of three planning scenarios for three different performance groups (entry-, intermediate- and elite-level athletes). These scenarios are consist of a plan for nine weeks, plan for nine weeks with two weeks boot camp, and full general preparation period lasting 12 weeks.

Besides the demonstration, we compared the plans with manually produced plans that have been provided by an expert in the sports domain, who is national coach of kickboxing for Czechia. The comparisons indicate that the automatically generated plans are more detailed, and individual and that their generation can save a lot of experts time. Further, the plans comparison showed us that the expert's plans were designed from an organisational point of view to be able to manage a group of athletes. However, the individual approach to planning has been made ad-hoc. In other words, athletes who have individual training obtain the training plan on the fly from the coaches experience. This fact showed that there is a place for our planning tool as it enables coaches to define individual training plans in advance with minimal effort.

Finally, we presented our planning method and its generated plans to the expert who provided us with his feedback and evaluation. The expert's stand towards our planning approach has been positive, and he expressed willingness to try the approach himself in practice. More importantly, he affirmed soundness of given plans. However, there has been made a few remarks, which could further improve our plans. For example, the expert proposed to create an additional constraint that would limit training units with the same body part attributes allocated in a continuous sequence. Additionally, there has been a suggestion to add explicitly dedicated technical units. In our plans, we define slots for technical and regeneration units by using $notfree$ predicate, although, the expert would wish for including the technical side of training in full. This would mean to define various technical actions and integrate them into our domain. However, the purpose of this study is to deliver planning approach for physical preparation and adding the technical side of the training, which would provide specific technical actions, is beyond the scope of this research. However, it is an attractive proposition for future work.

From above, we provide a list of the main knowledge contributions and their critical assessment. In addition, we identified the research and the planning method advantages and limitations, which are presented below.

- **Encoding of sport science knowledge and expertise into an operational planning domain model.** Our domain model presents a significant advancement in sports training planning as it vastly speeds up the planning process. Besides, our research introduces a framework for the automatic generation of training plans for individual athletes that is based on current sports science literature. Consequently, the research approach offers the ability to produce highly individualised plans that are based on the current best practice in the field.

  Limitations. With regards to limitations, it is crucial to keep in mind that sports science is a broad ever-changing discipline, continually bringing new findings. For that reason, it is essential to refine and continually improve models to maintain the quality of the generated plans. This need to frequent updates is a current limitation, also in the light of the fact that the current solution does not provide a mean for the effective update of the encoded knowledge. Further, the introduced model has been designed for individual sports, and does not currently support team sports, where athletes have to cooperate and coordinate in order to allow the team to perform at its best.

- **Outlying sports performance quantification scheme (SPQS) that empowers us to convert athletes' testing results into physical attribute value.** Being able to identify athletes' physical attributes and therefore their physical state is essential for our planning model as it does not only provide insight into their physical performance but also enables us to determine domain actions, effects and initial and goal states. This has been achieved by designing a quantification scheme, called SPQS. The SPQS enables us to acquire well-defined values that represent athletes physical abilities. After a thorough literature survey, no other similar method was found that would allow for quantifying and encoding athletes physical abilities.

Limitations. The chosen test battery, on which the SPQS is based, includes the minimum of tests to supply the required attributes. For that reason, the test battery can be improved on, and the domain experts are encouraged to add or modify the test battery provided by this research according to their needs. It may be the case that the chosen test battery does not work well for different kind of sport disciplines: in that case, a complete new battery has to be identified, but the overall approach can be still exploited.

- **Validation and evaluation of the planning approach and its training plans**.

  We designed a technique for validating and assessing the quality of the plans generated by our planning approach. In particular, generated plans have been compared against hand-made plans produced by a professional coach with more than 20 years of experience, and who is kickboxing national coach for Czechia. The coach validated and evaluated the plans as satisfactory. Further, the comparison provided us with the understanding that our planning approach presents feasible plans, and therefore could have the potential to deliver significant advancement in training planning.

  Limitations. The expert highlighted that the current technique does not interleave the training of different body parts. Instead, it seems to focus on repeating exercises for a single part of the body, before moving to the next one. This has to be improved in order to guarantee a more consistent improvement of the general body performance of an athlete. A further limitation lies in the fact that generated plans cannot be easily modified / adapted by human experts, but have to be accepted as they are, or completely regenerated.

Summarising, the case study and expert evaluation supplied us with evidence that our proposed planning method is valid, and if used in practice, it could lead to higher performing athletes.

On the final note, this thesis represents the first principled study of the area, and it is understood that it may be beneficial to foster future work on this interdisciplinary topic, which is discussed in the next section.

Future Work

The results of the experimental analysis, and of the validation process with the domain expert, suggest a number of possible avenues for future works, that we prioritise and detail below.

1. **Refine models to implement request from the domain experts.** Following the discussion with the domain expert, we plan to improve the models for kickboxing accordingly, by encoding additional constrains on actions' body part attribute, and adding technical and regeneration side of the training planning. Refining of the models is a top priority, since it will allow to provide exploitable training plans for the considered field. Further, it will enable the expert to conduct the first trial in practice.

2. **Conduct clinical trial of the planning approach.** The clinical trial could provide us with further insight into the advantages and limitations of our approach. In particular, it may provide indications whether the proposed techniques are able to effectively cope with the variability of conditions faced by athletes during training. The clinical trail would provide a solid ground for assessing the impact of our approach, and could highlight aspects of the framework that need to be revisited or improved. We are currently discussing with the domain expert to explore the possibility of running the trial with some of his athletes.

3. **Assess the generalisability of the approach for other sports.** The design approach is general in principle, but there may be sports domain for which additional constraints and / or peculiar practices may require a significant reformulation of the models. Nonetheless, adaptation for other sports could result in a wider spread of the planning approach, which could attract additional resources for our research. However, to be able to modify the model, there is a need for experts in specific sports, who would offer their expertise.

4. **Refine the models to better reflect improvement curves of athletes.** To better simulate the real improvement of an athlete performance due to the performed training, we are interested in investigating different ways to encode the improvement aspects. For example, it would be interesting to implement non-linear improvements, that dynamically depends on fluents and time spent in training. Implementation of such functionality is highly demanding for time resources; however, it would add to the model autonomy and further improve the quality of generated plans.

   Informed by the results of the above mentioned future work, it may be the case that models have to be refined to better reflect the improvement curve of athletes.

5. **Extend the experimental analysis using different planning engines and more complex PDDL features.** We are interested in assessing if the use of different planning engines can lead to significantly different plans, and whether such differences can enrich the generated training plans. Similarly, the use of a different set of PDDL features may lead to more complex training plans, or plans that better suit the requirements of a given athlete. While this is of low impact on the application domain, it may shed some light on the characteristics of the encoded models, and on the challenges that they provide for the state of the art of domain-independent planning.

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APPENDICES

A. EXAMPLES OF ABSTRACT ATPS

Period																											**Period**
Coach																											**Coach**
Athlete																											**Athlete**
Performance Goal	Gold Medal at WAKO World Champion Ship																										**Performance Goal**
Training Priorities	Technical/Tactical skills; Explosiveness																										**Training Priorities**
Microcycles (WEEKS)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	**Microcycles**
Competition												Litomerice				Czech Cup					EUCh ISKA						**Competition**
Importance of Competition (1-5)												1				2					4						**Importance of Competition (1-5)**
Training Camps																											**Training Camps**
Physical Testing																											**Physical Testing**
Technical / Tactical Evaluation																											**Technical / Tactical Evaluation**
Macrocycles	1st Cycle																										**Macrocycles**
Period	Preparation																		Competition					Transition			**Period**
Phase	General Preparation												Specific Preparation											Recovery			**Phase**
Duration of phases	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	1	2	3	4	5	1	2	3	**Duration**
Energy Systems																											**Energy Systems**
Aerobic System	L	L	L	L	L	L																					**Aerobic System**
Anaerobic System (Power)					L	L	L	D	D	D	D	D	M	M	M	D	D	D	M	M	M	M	M	R	R	R	**Anaerobic Power: plyometrics**
Volume (hours)	6	6	6	6	8	8	2	2	2	4	4	4	2	2	2	3	3	3	2	2	2	2	2	0	0	0	**Volume (hours)**
Muscular Development																											**Muscular Development**
Strenght Endurance	D	D	D	D	D	D																					**Strenght Endurance**
Maximal Strenght					D	D	D			D	D	D															**Maximal Strenght**
Explosiveness / speed strenght endurance	D	D	D	D	D	D	M	M	M	D	D	D	D	D	D	D	D	D	M	M	M	M	M	R	R	R	**Explosiveness**
Volume (hours)	4	4	4	4	6	6	4	4	4	4	4	4	2	2	2	3	3	3	4	2	2	2	2	1	1	1	**Volume (hours)**
Technical/Tactical skills																											**Technical/Tactical skills**
Offence					D	D	D	D	D	D	D	D	D	D	D	D	D	D	M	M	M	M	M	R	R	R	**Offence**
Defence					D	D	D	D	D	D	D	D	D	D	D	D	D	D	M	M	M	M	M	R	R	R	**Defence**
Counter attacks					D	D	D	D	D	D	D	D	D	D	D	D	D	D	M	M	M	M	M	R	R	R	**Counter attacks**
Footwork					D	D	D	D	D	D	D	D	D	D	D	D	D	D	M	M	M	M	M	R	R	R	**Footwork**
Sparings					D	D				D	D	D	D			D	D	D	M	M	M	M	M	R	R	R	**Sparings**
Volume (hours)	0	0	0	0	6	6	4	4	4	6	6	6	8	8	8	8	8	8	6	4	3	4	6	0	0	0	**Volume (hours)**
Regeneration																											**Regeneration**
Relaxation																											**Relaxation**
Volume (hours)	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	**Volume (hours)**
Competition (hours)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	3	0	0	0	0	0	**Competition (hours)**
Total Volume (hours)	11	11	11	11	21	21	10.5	10.5	10.5	10.5	10.5	11.5	12.5	12.5	12.5	14.5	15.5	14.5	12.5	8.5	7.5	8.5	10.5	2	2	2	**Total Volume (hours)**

Fig. A.1. The annual training plan according to AIBA [39]

B. EXPERIMENTS RESULTS

Table B.1.
Number of actions for entry athlete for all three scenarios. ”entry 45s” - plan for entry athlete for 9 weeks with 45 slots ”entry b” - plan for entry athlete for 9 weeks including boot camp ”entry 12w” - plan for entry athlete for 12 weeks

Action Name and Body Part	entry 45s	entry b	entry w12
AEROBICTU	4	6	5
AGILITYTU	1	0	1
ANAEROBICTU LOWER_LIMBS	1	0	0
ANAEROBICTU MID_BODY	0	2	0
ANAEROBICTU UPPER_LIMBS	0	0	0
CIRCUITTU LOWER_LIMBS	0	1	1
CIRCUITTU MID_BODY	0	5	4
CIRCUITTU UPPER_LIMBS	0	3	2
FARTLEKTU LOWER_LIMBS	2	1	2
FARTLEKTU MID_BODY	0	3	1
FARTLEKTU UPPER_LIMBS	5	4	5
INTERVALTU LOWER_LIMBS	2	1	2
INTERVALTU MID_BODY	1	0	2
INTERVALTU UPPER_LIMBS	2	4	3
MAXIMALSTRENGTHTU LOWER_LIMBS	2	2	2
MAXIMALSTRENGTHTU MID_BODY	0	1	0
MAXIMALSTRENGTHTU UPPER_LIMBS	1	2	2
STRENGHTENDURANCETU LOWER_LIMBS	1	0	1
STRENGHTENDURANCETU MID_BODY	1	4	1
STRENGHTENDURANCETU UPPER_LIMBS	3	2	0
POLYMETRICSTU LOWER_LIMBS	1	5	2
POLYMETRICSTU MID_BODY	0	1	0
POLYMETRICSTU UPPER_LIMBS	0	2	0
MAXIMUMSPEEDTU LOWER_LIMBS	0	0	0
MAXIMUMSPEEDTU MID_BODY	0	0	0
MAXIMUMSPEEDTU UPPER_LIMBS	0	0	0
CROSSTU LOWER_LIMBS	0	0	0
CROSSTU MID_BODY	0	0	0
CROSSTU UPPER_LIMBS	0	0	0

Table B.2.
Number of actions for intermediate athlete for all three scenarios. ”inter 45s” - plan for intermediate athlete for 9 weeks with 45 slots ”inter b” - plan for intermediate athlete for 9 weeks including boot camp ”inter 12w” - plan for intermediate athlete for 12 weeks

Action Name and Body Part	inter 45s	inter b	inter 12w
AEROBICTU	4	7	3
AGILITYTU	0	1	4
ANAEROBICTU LOWER_LIMBS	0	0	0
ANAEROBICTU MID_BODY	0	1	4
ANAEROBICTU UPPER_LIMBS	1	1	1
CIRCUITTU LOWER_LIMBS	1	3	1
CIRCUITTU MID_BODY	1	3	5
CIRCUITTU UPPER_LIMBS	5	6	5
FARTLEKTU LOWER_LIMBS	4	5	6
FARTLEKTU MID_BODY	3	5	1
FARTLEKTU UPPER_LIMBS	2	1	2
INTERVALTU LOWER_LIMBS	2	2	5
INTERVALTU MID_BODY	2	2	4
INTERVALTU UPPER_LIMBS	4	2	4
MAXIMALSTRENGTHTU LOWER_LIMBS	1	2	2
MAXIMALSTRENGTHTU MID_BODY	1	1	2
MAXIMALSTRENGTHTU UPPER_LIMBS	1	1	1
STRENGHTENDURANCETU LOWER_LIMBS	2	3	3
STRENGHTENDURANCETU MID_BODY	2	3	1
STRENGHTENDURANCETU UPPER_LIMBS	1	2	2
POLYMETRICSTU LOWER_LIMBS	4	6	2
POLYMETRICSTU MID_BODY	4	3	2
POLYMETRICSTU UPPER_LIMBS	0	2	0
MAXIMUMSPEEDTU LOWER_LIMBS	0	0	0
MAXIMUMSPEEDTU MID_BODY	0	0	0
MAXIMUMSPEEDTU UPPER_LIMBS	0	0	0
CROSSTU LOWER_LIMBS	0	0	0
CROSSTU MID_BODY	0	0	0
CROSSTU UPPER_LIMBS	0	0	0

Table B.3.
Number of actions for elite athlete for all three scenarios. "elite 45s" - plan for elite athlete 9 weeks with 45 slots "elite b" - plan for elite athlete 9 weeks including boot camp "elite 12w" - plan for elite athlete for 12 weeks

Action Name and Body Part	elite 45s	elite b	elite 12w
AEROBICTU	3	8	6
AGILITYTU	1	2	1
ANAEROBICTU LOWER_LIMBS	0	0	0
ANAEROBICTU MID_BODY	1	0	1
ANAEROBICTU UPPER_LIMBS	0	1	2
CIRCUITTU LOWER_LIMBS	3	7	7
CIRCUITTU MID_BODY	4	2	1
CIRCUITTU UPPER_LIMBS	1	6	1
FARTLEKTU LOWER_LIMBS	1	3	1
FARTLEKTU MID_BODY	5	1	3
FARTLEKTU UPPER_LIMBS	2	5	4
INTERVALTU LOWER_LIMBS	1	2	7
INTERVALTU MID_BODY	5	2	2
INTERVALTU UPPER_LIMBS	1	2	3
MAXIMALSTRENGTHTU LOWER_LIMBS	0	0	1
MAXIMALSTRENGTHTU MID_BODY	1	2	3
MAXIMALSTRENGTHTU UPPER_LIMBS	5	9	4
STRENGHTENDURANCETU LOWER_LIMBS	4	0	0
STRENGHTENDURANCETU MID_BODY	0	1	0
STRENGHTENDURANCETU UPPER_LIMBS	1	3	0
POLYMETRICSTU LOWER_LIMBS	0	1	2
POLYMETRICSTU MID_BODY	2	0	1
POLYMETRICSTU UPPER_LIMBS	3	8	3
MAXIMUMSPEEDTU LOWER_LIMBS	0	0	0
MAXIMUMSPEEDTU MID_BODY	0	0	0
MAXIMUMSPEEDTU UPPER_LIMBS	0	0	0
CROSSTU LOWER_LIMBS	0	0	0
CROSSTU MID_BODY	0	0	0
CROSSTU UPPER_LIMBS	0	0	0

C. FULL EXAMPLE OF RAW PLAN

The figure 4.1 provides an example of a plan for entry athlete plan, which lasts for nine weeks, and it is in its raw form. The rest of the raw experimental plans can be found at a Github repository at the following link:

`https://github.com/skerovs/SportDomain/invitations`.

```
; Time 17.58
; MetricValue -91.50

0:   (ANAEROBICTU SLOT43 LOWER_LIMBS SLOT42 SLOT44 W9) [1]
0:   (AGILITYTU SLOT41 SLOT40 SLOT42 W9) [1]
0:   (MAXIMALSTRENGTHTU SLOT45 LOWER_LIMBS SLOT44 DUMMY_SLOT W9) [1]
0:   (AEROBICTU SLOT16 SLOT15 SLOT17 W4) [1]
0:   (INTERVALTU SLOT3 UPPER_LIMBS SLOT2 SLOT4 W1) [1]
0:   (FARTLEKTU SLOT25 UPPER_LIMBS SLOT24 SLOT26 W5) [1]
0:   (AEROBICTU SLOT21 SLOT20 SLOT22 W5) [1]
0:   (STRENGHTENDURANCETU SLOT11 UPPER_LIMBS SLOT10 SLOT12 W3) [1]
0:   (INTERVALTU SLOT18 MID_BODY SLOT17 SLOT19 W4) [1]
0:   (FARTLEKTU SLOT8 UPPER_LIMBS SLOT7 SLOT9 W2) [1]
0:   (INTERVALTU SLOT10 LOWER_LIMBS SLOT9 SLOT11 W2) [1]
0:   (INTERVALTU SLOT26 UPPER_LIMBS SLOT25 SLOT27 W6) [1]
0:   (FARTLEKTU SLOT33 UPPER_LIMBS SLOT32 SLOT34 W7) [1]
0:   (FARTLEKTU SLOT15 UPPER_LIMBS SLOT14 SLOT16 W3) [1]
0:   (MAXIMALSTRENGTHTU SLOT36 LOWER_LIMBS SLOT35 SLOT37 W8) [1]
0:   (STRENGHTENDURANCETU SLOT6 UPPER_LIMBS SLOT5 SLOT7 W2) [1]
0:   (STRENGHTENDURANCETU SLOT28 LOWER_LIMBS SLOT27 SLOT29 W6) [1]
0:   (STRENGHTENDURANCETU SLOT23 MID_BODY SLOT22 SLOT24 W5) [1]
0:   (MAXIMALSTRENGTHTU SLOT31 UPPER_LIMBS SLOT30 SLOT32 W7) [1]
0:   (FARTLEKTU SLOT5 LOWER_LIMBS SLOT4 SLOT6 W1) [1]
0:   (STRENGHTENDURANCETU SLOT1 UPPER_LIMBS DUMMY_SLOT SLOT2 W1) [1]
0:   (AEROBICTU SLOT13 SLOT12 SLOT14 W3) [1]
0:   (FARTLEKTU SLOT20 LOWER_LIMBS SLOT19 SLOT21 W4) [1]
0:   (AEROBICTU SLOT30 SLOT29 SLOT31 W6) [1]
0:   (POLYMETRICSTU SLOT40 LOWER_LIMBS SLOT39 SLOT41 W8) [1]
0:   (INTERVALTU SLOT35 LOWER_LIMBS SLOT34 SLOT36 W7) [1]
0:   (FARTLEKTU SLOT38 UPPER_LIMBS SLOT37 SLOT39 W8) [1]
```

Fig. C.1. Raw plan output for an entry athlete, which lasts for 9 weeks and is made of 45 slots from which 27 are allocated.

D. FULL EXAMPLE OF SORTED PLAN

The figure D.1 provides an example of a plan, which was sorted by our script. The plan is made for an entry athlete, which lasts for nine weeks and is made of 45 slots from which 27 is allocated. The rest of the experimental sorted plans can be found at a Github repository at the following link:

`https://github.com/skerovs/SportDomain/invitations`.

```
; Time 17.58
; MetricValue -91.50

0:   (ANAEROBICTU SLOT43 LOWER_LIMBS SLOT42 SLOT44 W9) [1]
0:   (AGILITYTU SLOT41 SLOT40 SLOT42 W9) [1]
0:   (MAXIMALSTRENGTHTU SLOT45 LOWER_LIMBS SLOT44 DUMMY_SLOT W9) [1]
0:   (AEROBICTU SLOT16 SLOT15 SLOT17 W4) [1]
0:   (INTERVALTU SLOT3 UPPER_LIMBS SLOT2 SLOT4 W1) [1]
0:   (FARTLEKTU SLOT25 UPPER_LIMBS SLOT24 SLOT26 W5) [1]
0:   (AEROBICTU SLOT21 SLOT20 SLOT22 W5) [1]
0:   (STRENGHTENDURANCETU SLOT11 UPPER_LIMBS SLOT10 SLOT12 W3) [1]
0:   (INTERVALTU SLOT18 MID_BODY SLOT17 SLOT19 W4) [1]
0:   (FARTLEKTU SLOT8 UPPER_LIMBS SLOT7 SLOT9 W2) [1]
0:   (INTERVALTU SLOT10 LOWER_LIMBS SLOT9 SLOT11 W2) [1]
0:   (INTERVALTU SLOT26 UPPER_LIMBS SLOT25 SLOT27 W6) [1]
0:   (FARTLEKTU SLOT33 UPPER_LIMBS SLOT32 SLOT34 W7) [1]
0:   (FARTLEKTU SLOT15 UPPER_LIMBS SLOT14 SLOT16 W3) [1]
0:   (MAXIMALSTRENGTHTU SLOT36 LOWER_LIMBS SLOT35 SLOT37 W8) [1]
0:   (STRENGHTENDURANCETU SLOT6 UPPER_LIMBS SLOT5 SLOT7 W2) [1]
0:   (STRENGHTENDURANCETU SLOT28 LOWER_LIMBS SLOT27 SLOT29 W6) [1]
0:   (STRENGHTENDURANCETU SLOT23 MID_BODY SLOT22 SLOT24 W5) [1]
0:   (MAXIMALSTRENGTHTU SLOT31 UPPER_LIMBS SLOT30 SLOT32 W7) [1]
0:   (FARTLEKTU SLOT5 LOWER_LIMBS SLOT4 SLOT6 W1) [1]
0:   (STRENGHTENDURANCETU SLOT1 UPPER_LIMBS DUMMY_SLOT SLOT2 W1) [1]
0:   (AEROBICTU SLOT13 SLOT12 SLOT14 W3) [1]
0:   (FARTLEKTU SLOT20 LOWER_LIMBS SLOT19 SLOT21 W4) [1]
0:   (AEROBICTU SLOT30 SLOT29 SLOT31 W6) [1]
0:   (POLYMETRICSTU SLOT40 LOWER_LIMBS SLOT39 SLOT41 W8) [1]
0:   (INTERVALTU SLOT35 LOWER_LIMBS SLOT34 SLOT36 W7) [1]
0:   (FARTLEKTU SLOT38 UPPER_LIMBS SLOT37 SLOT39 W8) [1]
```

Fig. D.1. Sorted plan for an entry athlete with 45 slots

E. EXPERT PLANS EXAMPLES

In this appendix section, we provide an example of an expert plan in its full version. There are additional examples, which can be found at a Github repository at the following link `https://github.com/skerovs/SportDomain/invitations`. The plans are at the repository under following path: `\SportDomain\Analysis\DomainExpertsPlans`

Date	Day	Time	Place	Training Type
11/07/2016	Monday	18:00 - 20:00	Running Track Outside	Technique & Running
12/07/2016	Tuesday	18:00 - 19:00	Gym	Kicks
13/07/2016	Wednesday			
14/07/2016	Thursday	18:00 - 20:00	Running Track Outside	Technique & Running
15/07/2016	Friday	18:00 - 19:00	Gym	Pads
18/07/2016	Monday	18:00 - 20:00	Running Track Outside	Technique & Running
19/07/2016	Tuesday	18:00 - 20:00	Running Track Outside	10 km
20/07/2016	Wednesday			
21/07/2016	Thursday	18:00 - 20:00	Running Track Outside	Technique & Running
22/07/2016	Friday	18:00 - 19:00	Gym	Pads
24/07/2016				
25/07/2016	Monday	18:00 - 20:00	Running Track Outside	Alfabet 4x 400, 2x600, 4x400
26/07/2016	Tuesday	18:00 - 19:00	Gym	Kicks
27/07/2016	Wednesday			
28/07/2016	Thursday	18:00 - 20:00	Running Track Outside	Technique & Running
29/07/2016	Friday	18:00 - 19:00	Gym	Pads
31/07/2016				
01/08/2016	Monday	18:00 - 20:00	Running Track Outside	Technique & Running
02/08/2016	Tuesday	18:00 - 20:00	Running Track Outside	Technique & 10 km
03/08/2016	Wednesday			
04/08/2016	Thursday	Boot Camp		
05/08/2016	Friday	Boot Camp		
06/08/2016	Saturday	Boot Camp		
07/08/2016	Sunday	Boot Camp		
08/08/2016	Monday	18:00 - 20:00	Running Track Outside	Technique & Running
09/08/2016	Tuesday	18:00 - 19:00	Gym	Technique & Running
10/08/2016	Wednesday			
11/08/2016	Thursday	18:00 - 20:00	Running Track Outside	Technique & Running
12/08/2016	Friday	18:00 - 19:00	Gym	Pads

Fig. E.1. Plan produced by expert for 9 weeks first part.

Date	Day	Time	Place	Training Type
15/08/2016	Monday	18:00 - 20:00	Running Track Outside	Technique & Running
16/08/2016	Tuesday	18:00 - 19:00	Running Track Outside	Technique & Running
17/08/2016	Wednesday			
18/08/2016	Thursday	18:00 - 20:00	Running Track Outside	Technique & Running
19/08/2016	Friday	18:00 - 19:00	Gym	Pads
22/08/2016	Monday	18:00 - 20:00	Running Track Outside	Technique & Running
23/08/2016	Tuesday	18:00 - 19:00	Gym	Technique & Running
24/08/2016	Wednesday			
25/08/2016	Thursday	18:00 - 20:00	Running Track Outside	Half marathon 21,1 km
26/08/2016	Friday	18:00 - 19:00	Gym	Pads
29/08/2016	Monday	18:00 - 20:00	Running Track Outside	Technique & Running
30/08/2016	Tuesday	18:00 - 19:00	Gym	Kicks
31/08/2016	Wednesday			
01/09/2016	Thursday	18:00 - 20:00	Running Track Outside	Technique & Running
02/09/2016	Friday		Competition	
05/09/2016	Monday	18:00 - 20:00	Running Track Outside	Technique & Running
06/09/2016	Tuesday	18:00 - 19:00	Gym	Kicks
07/09/2016	Wednesday			
08/09/2016	Thursday	18:00 - 20:00	Running Track Outside	Technique & Running
09/09/2016	Friday	18:00 - 19:00	Gym	Pads

Fig. E.2. Plan produced by expert for 9 weeks second part.

F. EXAMPLES OF AUTOMATICALLY GENERATED PLANS

Out of the nine generated plans, we provide three plans in their visual form that is easier to read for coaches, which are entry-level athlete plan for nine weeks, intermediate-level athlete plan for nine weeks with boot camp, and elite-level athlete plan for 12 weeks. The rest of the plans can be found at a Github repository at the following link `https://github.com/skerovs/SportDomain/invitations`. They can be found in excel spreadsheets in locations:

- `\SportDomain\PlanResults\domain2.2\prob11\_elite`
- `\SportDomain\PlanResults\domain2.2\prob10\_inter`
- `\SportDomain\PlanResults\domain2.2\prob9\_entry`

	Week 1	Week 2	Week 3
Monday	STRENGHTENDURANCETU UPPER_LIMBS	STRENGHTENDURANCETU UPPER_LIMBS	STRENGHTENDURANCETU UPPER_LIMBS
Tuesday			
Wednesday	INTERVALTU UPPER_LIMBS	FARTLEKTU UPPER_LIMBS	AEROBICTU
Thursday			
Friday	FARTLEKTU LOWER_LIMBS	INTERVALTU LOWER_LIMBS	FARTLEKTU UPPER_LIMBS

	Week 4	Week 5	Week 6
Monday	AEROBICTU	AEROBICTU	INTERVALTU UPPER_LIMBS
Tuesday			
Wednesday	INTERVALTU MID_BODY	STRENGHTENDURANCETU MID_BODY	STRENGHTENDURANCETU LOWER_LIMBS
Thursday			
Friday	FARTLEKTU LOWER_LIMBS	FARTLEKTU UPPER_LIMBS	AEROBICTU

	Week 7	Week 8	Week 9
Monday	MAXIMALSTRENGTHTU UPPER_LIMBS	MAXIMALSTRENGTHTU LOWER_LIMBS	AGILITYTU
Tuesday			
Wednesday	FARTLEKTU UPPER_LIMBS	INTERVALTU MFARTLEKTU UPPER_LIMBSII	ANAEROBICTU LOWER_LIMBS
Thursday			
Friday	INTERVALTU LOWER_LIMBS	POLYMETRICSTU LOWER_LIMBS	MAXIMALSTRENGTHTU LOWER_LIMBS

Fig. F.1. Entry athlete plan 9 weeks with 45 slots.

	Week 1
Monday	FARTLEKTU LOWER_LIMBS
Tuesday	POLYMETRICSTU LOWER_LIMBS
Wednesday	STRENGHTENDURANCETU MID_BODY
Thursday	AEROBICTU
Friday	FARTLEKTU LOWER_LIMBS

	Bootcamp Week 2		
	Morning	Afternoon	Evening
Monday	AEROBICTU	MAXIMALSTRENGTHTU UPPER_LIMBS	CIRCUITTU UPPER_LIMBS
Tuesday	ANAEROBICTU UPPER_LIMBS	FARTLEKTU LOWER_LIMBS	STRENGHTENDURANCETU LOWER_LIMBS
Wednesday	AEROBICTU	CIRCUITTU MID_BODY	INTERVALTU UPPER_LIMBS
Thursday	POLYMETRICSTU LOWER_LIMBS	CIRCUITTU MID_BODY	STRENGHTENDURANCETU UPPER_LIMBS
Friday	FARTLEKTU MID_BODY	POLYMETRICSTU MID_BODY	FREE

	Bootcamp Week 3		
	Morning	Afternoon	Evening
Monday	STRENGHTENDURANCETU LOWER_LIMBS	AEROBICTU	CIRCUITTU UPPER_LIMBS
Tuesday	AEROBICTU	CIRCUITTU UPPER_LIMBS	INTERVALTU LOWER_LIMBS
Wednesday	FARTLEKTU MID_BODY	AEROBICTU	POLYMETRICSTU LOWER_LIMBS
Thursday	CIRCUITTU UPPER_LIMBS	MAXIMALSTRENGTHTU MID_BODY	POLYMETRICSTU LOWER_LIMBS
Friday	FARTLEKTU UPPER_LIMBS	STRENGHTENDURANCETU LOWER_LIMBS	FREE

	Week 4	Week 5	Week 6
Monday	CIRCUITTU UPPER_LIMBS	INTERVALTU UPPER_LIMBS	AEROBICTU
Tuesday	FARTLEKTU LOWER_LIMBS	AEROBICTU	FARTLEKTU MID_BODY
Wednesday	STRENGHTENDURANCETU UPPER_LIMBS	STRENGHTENDURANCETU MID_BODY	STRENGHTENDURANCETU MID_BODY
Thursday	MAXIMALSTRENGTHTU LOWER_LIMBS	CIRCUITTU UPPER_LIMBS	POLYMETRICSTU LOWER_LIMBS
Friday	POLYMETRICSTU MID_BODY	POLYMETRICSTU UPPER_LIMBS	CIRCUITTU LOWER_LIMBS

	Week 7	Week 8	Week 9
Monday	POLYMETRICSTU MID_BODY	FARTLEKTU MID_BODY	CIRCUITTU LOWER_LIMBS
Tuesday	INTERVALTU LOWER_LIMBS	POLYMETRICSTU LOWER_LIMBS	INTERVALTU MID_BODY
Wednesday	FARTLEKTU LOWER_LIMBS	ANAEROBICTU MID_BODY	POLYMETRICSTU UPPER_LIMBS
Thursday	CIRCUITTU LOWER_LIMBS	CIRCUITTU MID_BODY	AGILITYTU
Friday	INTERVALTU MID_BODY	MAXIMALSTRENGTHTU LOWER_LIMBS	FARTLEKTU MID_BODY

Fig. F.2. Intermediate athlete plan 9 weeks including boot camp.

		Week 1	Week 2	Week 3
Monday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	INTERVALTU MID_BODY	POLYMETRICSTU UPPER_LIMBS	STRENGHTENDURANCETU MID_BODY
Tuesday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	POLYMETRICSTU UPPER_LIMBS	AEROBICTU	FARTLEKTU MID_BODY
Wednesday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	AEROBICTU	AEROBICTU	INTERVALTU LOWER_LIMBS
Thursday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	AEROBICTU	INTERVALTU MID_BODY	FARTLEKTU MID_BODY
Friday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	STRENGHTENDURANCETU LOWER_LIMBS	STRENGHTENDURANCETU UPPER_LIMBS	CIRCUITTU LOWER_LIMBS

		Week 4	Week 5	Week 6
Monday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	INTERVALTU MID_BODY	AEROBICTU	INTERVALTU LOWER_LIMBS
Tuesday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	AEROBICTU	FARTLEKTU UPPER_LIMBS	MAXIMALSTRENGTHTU MID_BODY
Wednesday	Morning	NOT FREE	INTERVALTU UPPER_LIMBS	CIRCUITTU LOWER_LIMBS
	Afternoon	FARTLEKTU MID_BODY	NOT FREE	NOT FREE
Thursday	Morning	NOT FREE	CIRCUITTU UPPER_LIMBS	INTERVALTU LOWER_LIMBS
	Afternoon	FARTLEKTU LOWER_LIMBS	MAXIMALSTRENGTHTU UPPER_LIMBS	FARTLEKTU UPPER_LIMBS
Friday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	INTERVALTU UPPER_LIMBS	NOT FREE	NOT FREE

		Week 7	Week 8	Week 9
Monday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	POLYMETRICSTU UPPER_LIMBS	INTERVALTU UPPER_LIMBS	POLYMETRICSTU UPPER_LIMBS
Tuesday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	FARTLEKTU UPPER_LIMBS	POLYMETRICSTU LOWER_LIMBS	INTERVALTU LOWER_LIMBS
Wednesday	Morning	INTERVALTU LOWER_LIMBS	INTERVALTU LOWER_LIMBS	ANAEROBICTU UPPER_LIMBS
	Afternoon	NOT FREE	NOT FREE	NOT FREE
Thursday	Morning	CIRCUITTU LOWER_LIMBS	CIRCUITTU LOWER_LIMBS	CIRCUITTU LOWER_LIMBS
	Afternoon	INTERVALTU LOWER_LIMBS	FARTLEKTU UPPER_LIMBS	AGILITYTU
Friday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	NOT FREE	NOT FREE	NOT FREE

		Week 10	Week 11	Week 12
Monday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	MAXIMALSTRENGTHTU MID_BODY	INTERVALTU MID_BODY	MAXIMALSTRENGTHTU UPPER_LIMBS
Tuesday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	ANAEROBICTU MID_BODY	MAXIMALSTRENGTHTU UPPER_LIMBS	CIRCUITTU LOWER_LIMBS
Wednesday	Morning	CIRCUITTU LOWER_LIMBS	CIRCUITTU MID_BODY	ANAEROBICTU UPPER_LIMBS
	Afternoon	NOT FREE	NOT FREE	NOT FREE
Thursday	Morning	MAXIMALSTRENGTHTU LOWER_LIMBS	POLYMETRICSTU UPPER_LIMBS	POLYMETRICSTU LOWER_LIMBS
	Afternoon	POLYMETRICSTU MID_BODY	MAXIMALSTRENGTHTU UPPER_LIMBS	MAXIMALSTRENGTHTU MID_BODY
Friday	Morning	NOT FREE	NOT FREE	NOT FREE
	Afternoon	NOT FREE	NOT FREE	NOT FREE

Fig. F.3. Elite athlete plan 12 weeks.