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Real-time monitoring of progress in object-aware business processes

Master thesis at Ulm University

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»Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it.«

– H. James Harrington

Abstract

A high degree of competition require companies to constantly improve and further develop their business processes (BP). Therefore, optimisations and improvements are an important key element in this endeavour. The monitoring of a BP should detect complications and errors quickly to support this objective. Two approaches can be pursued to achieve this: real-time, also called online, monitoring and offline monitoring. A sub task of real-time monitoring is determining the current progress of a business process.

Business processes in PHILharmonicFlows consist of objects with lifecycles, describing the behaviour of an object, and coordination processes, which organise and structure the overall business process. The composition of an object-aware business processes is extremely complex. Many instances of objects and lifecycles exist. Running concurrently to each other. Further, there are coordination constraints between objects that restrict certain executions of the overall business process. Due of the complexity, there is no intuitive solution for real-time monitoring of progress in an object-aware business process. Progress of the overall business process consists of a combination of the individual progress measures to these contributing parts. Therefore, a method called **P**HILharmonicFlows **P**rogress **D**etermination (PPD-Method) is developed that can be used to determine the progress of object-aware processes. The progress representation provides users with knowledge of the current status. In addition, standstills can be detected quickly and subsequently remedied.

As a first step, the PPD-Method uses a fixed snapshot of a business process, taken during execution, to determine progress. This is called a static progress determination and reduces the complexity of the calculation. Based on the static determination, the dynamic aspect of progress execution can be incorporated into the progress determination, such as instantiation of an object or state changes. This lead to dynamic determination of progress. The definition of progress for object-aware processes i.e what constitutes progress, offers several options. Each option is thoroughly assessed and evaluated. According on the metaphor of a progress bar and the structure of the business process, design choices for progress determination for the PPD-Method are identified based on the best option. Finally, this thesis develops algorithms as part of the PPD-Method for the static determination of object lifecycle progress.

Acknowledgement

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Special thanks go to my supervisor Sebastian Steinau, who allowed me to perform this work in the best possible conditions. I am infinitely grateful to him for sharing with me his knowledge and for his support at any time of day with this master thesis.

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Contents

1 Introduction

Monitoring can be used to discover problems and optimisation potential of a business processes. Additionally, real-time monitoring can support the users of the business process during the execution. Real-time monitoring can display the current state of the business process or calculate which sub-process (activity) is on time, at risk or overdue. When an alarm is triggered for an activity (or for the whole business process) because one part of the process has received the mark on risk, it is possible to take timely action to prevent receiving the mark overdue. Monitoring in some Business Process Management (BPM) tools already implement these functions to support the process. Another way to monitor and support the process is to represent the progress of the process. However, there are currently very few BPM tools that have capabilities for real-time process monitoring. The measurement of progress is nonexistent in practice. For this reason, a method is being developed for object-aware business process management and its implementation PHILharmonicFlows.

1.1 Motivation

Progress measurement in a business process offers the advantage for all user groups to easily check the current status. Progress determination has different viewpoints for different stakeholders. An employee is mainly interested in the progress of her work. A manager wants to know the progress of the entire business process. And a customer is interested in the progress of her order. In general, all stakeholders in a business process are keen on progress representation.
Further, progress determination can give users a better overview of (completed and pending) work especially if being involved in a business process with several employees. In addition, the expected progress can be compared with the target status at any time. If

the actual progress differs significantly from the target progress, alarms can be triggered. In this way, the effects of possible complications can be clarified earlier. With this early problem identification, ad-hoc changes and optimisations can be made. If a process in a certain activity always takes significantly longer, analyses can be started to optimise future processes directly at the affected position. Additionally, the current progress can be used to predict the duration of the entire process in order to plan the start of future depending processes. Further, the current progress can be used to predict when a result of the process can be expected. This idea of just-in-time becomes more and more common in almost every area of businesses and production. However, most business process management tools do not provide a sufficient and timely progress measurement and determination. Therefore, this thesis develops and discusses methods for a progress determination of an object-aware business process.

1.2 Problem statement

Several challenges to calculate and define progress metrics in PHILharmonicFlows exist. First, no known measures for object-aware progress exists. Additionally, progress can be interpreted in different ways. Progress is often described as fundamental improvements through significant changes in existing conditions. However, there is no generally accepted definition of the term progress. In addition, measuring points are missing, and methods for determining the actual and target value are required. A time delay in the calculation of the progress or estimation problems of the actual and target data can occur. Defining progress in PHILharmonicFlows is the first challenge of real-time monitoring of progress in object-aware business processes. This includes questions such as: What constitutes 0 or 100 percent progress? How is progress measured? What are the measuring points? What are the general requirements and design goals for calculating progress?
Second, the structure of an object-aware business process (lifecycles and coordination) is extremely complex. No generally intuitive or simple solution exists. Several configurations and constellations of processes (lifecycles and coordination) exist. Thus, another challenge is to define metrics or definitions to determine progress for all possible constellations including all edge and special cases. In addition, the progress of many individual business processes (lifecycles and coordination) must be merged depending on the situation to determine overall progress.
Many small design details have long-term effects. The result of this thesis is the foundation on which all further work for online monitoring of object-aware business process is based. For this reason, the topic of this thesis is focused on determining the progress of lifecycles. The determination of progress in a lifecycle is covered in this

thesis in its complete depth of detail. The aim is to avoid open questions about the determination of progress in a lifecycle.

1.3 Contribution

The first part of the contribution of this thesis is the research of progress definitions in software management and other approaches.
Secondly, requirements for the basic conditions of progress calculation, determination and representation are defined.
Thirdly, after progress definition for object-aware processes is elicited. Based on the metaphor of progress bar and the structure of the business process, design choices for progress determination are identified. The best design choice is thoroughly assessed and integrated into a method to determine the overall progress of the PPD-Method. This is an acronym for **P**HILharmonicFlows **P**rogress **D**etermination Method.
Finally, algorithms are developed that implement the PPD-Method for object lifecycles. The result of this algorithm is the calculation of the actual, current progress of a lifecycle process instance in percent in real-time.

1.4 Outline

This thesis is structured as follows. In Chapter 2 the fundamentals for this thesis are introduced to allow for a better understanding of its context. First, general monitoring of business processes is described. Second, the framework PHILharmonicFlows with all necessary components is introduced. Further, several progress determination methods from software management are described. Finally, the existing V-Model from software management is transcribed into a modified V-Model to provide a basis for the formulation of the research questions.
In Chapter 3, BPM tools are compared in regard to their monitoring capabilities. Further, different possibilities of graphical representations of progress are discussed.
In Chapter 4, the research questions to determine progress in an object-aware business process tool like PHILharmonicFlows are discussed. First, the research context is described and the major research domains with their research questions are introduced. Second, the research focus is defined in detail. Therefore, requirements for real-time progress calculation are specified. Further, the defined research questions are discussed according to the design of the newly developed V-Model. Lastly, all results of the research question are joined together in an algorithm called PPD-Method. This algorithm is

applied to several lifecycles for examples.
In Chapter 5, a summery about the results of this thesis is given. Finally, the further work of progress determination in an object-aware business process is described.

2 Background

This Chapter describes the basic concepts and notions of object-aware process management and monitoring. Every component that exists in a business process is described by an object. Each object has a lifecycle. In this lifecycle, the behaviour of the object is described. Only an object does not describe a business process. Therefore, the coordination processes are needed, which defines the structure of the business process with their objects.

2.1 Monitoring

A possible definition of monitoring in relation to business processes can be found in Definition 1. This is the most general term and includes the different types of monitoring. There are numerous definitions in the literature, but all of them include the statement that one needs to gain insight into the actual performance of the process.

> **Definition 1.** Monitoring [2]
> ≪Process monitoring is about using the data generated by the execution of a business process in order to extract insights about the actual performance of the process.≫

There exist two subcategories of process monitoring. The first one is offline process monitoring, which is given in Definition 2. The second is Online Process Monitoring, which is given in Definition 3.

> **Definition 2.** Offline Process Monitoring [2]
> ≪Offline process monitoring is concerned with the analysis of historic process executions. The input for offline process monitoring are event logs covering a set of cases completed during a particular period of time, for instance a month,

a quarter or a full year. Offline process monitoring techniques provide a picture of the performance of the process, the reasons for poor performance or for undesirable performance variations, and the conformance of the process with respect to certain rules or expected behaviour.≫

One of the first steps in monitoring is generally the analysis of the process after a lot of runs. To use this type of monitoring, the system or process does not need to be running or executing at the same time as the analyse of the process takes place. For this reason, this is referred to as offline process monitoring. In this type of monitoring, the generated log data of the process is analysed and evaluated after execution of a business process. The goal is to generate a report about the execution of the process to record possible problems and improvements. With a look into the past (150 years before), a successful process improvement through the manual analysis of log entries can be shown using the example of commercial shipping. After years of collecting data about the winds, currents, temperature and the weather in context of certain seasons on the seas. This allowed drawing ship charts (called sailing directions) by analysing these data. After years of standstill and as all other technical possibilities were exhausted, this analysis resulted in significant savings in time and money. The goal of any BPM monitoring is to improve an existing process. Today there are a lot of tools for analysing this data. Together with the log data and these tools, reports for offline monitoring can be created. The reports can be used to detect problems or bugs in the process. In the following the process can be improved with the findings from the offline monitoring.

After successful offline process monitoring, the next phase of the project may be online process monitoring. Even though both variants are not trivial, online process monitoring is even more challenging.

Definition 3. Online Process Monitoring [2]
≪Online process monitoring is concerned with the assessment of the performance of currently running process instances. The main input for process monitoring are (incomplete) traces of ongoing cases. Online process monitoring techniques produce real-time pictures of the performance of ongoing cases, generate alarms or trigger counteractions whenever certain performance objectives or compliance rules are not fulfilled, e.g., when a customer request remains unreplied beyond a given period of time.≫

In literature, the term online process monitoring was also defined. In this thesis, online process monitoring is referred to as real-time monitoring. One aim of real-time monitoring is the description of the business process during run-time. For example, this includes determining which sub-processes are at risk of being delayed or trigger alarms for errors and bugs during run-time. There, several challenges exists that need to be overcome.

In comparison of offline process monitoring to real-time monitoring the main input are incomplete traces or logs of ongoing sub-processes.

2.2 Object-aware process management

An object-aware business process is based on objects, which store data in the form of attributes. Definition 4 describes the properties of object-aware process management system.

> **Definition 4.** OBJECT-AWARE [3]
> ≪An object-aware process management system denotes a process- and object-aware information system with a tight integration of the process and the data perspective.≫

As a running example, a scenario is described in Example 1. Using this example, the components an object-aware business process are explained in the following. The scenario of the running example is a the recruitment of new employees.

Example 1: Recruitment Business Process
≫A company has an open position for which it wants to hire a suitable candidate. For this purpose, a company employee creates a job offer and publishes it (e.g., on the company website). For this job offer, interested persons may create applications. Applications may be created as long as the job offer is not closed, i.e, applications may arrive at different points in time at the company. For each applications that is sent to the company, an evaluation is started. Company experts must create reviews for the application and give a recommendation on whether to invite the applicant for an interview or reject him outright. The overall recommendation requires at least three reviews and a majority of 50 percent or more in favour of the applicant for an invite recommendation. Depending on the availability of the company experts and the arrival date of the respective application, reviews may be created and completed at different points in time. If the overall recommendation favours the rejection of an applicant, the corresponding application is rejected. If the reviews are in favour of the applicant, the applicant must be invited to at least one interview to further substantiate the suitability of the applicant for the open job offer. If the majority of interviews recommend hiring the applicant, the application may be accepted, otherwise the application is rejected. Ties are resolved in favour of acceptance. At least one must be performed. However, only one application may be accepted for each job offer. Should an applicant have been hired, the job offer is closed and given

the status position filled. Other applicants must consequently be rejected. The job offer may be closed at any time as long as at least one application has been sent to the company. If, after a reasonable amount of time, no suitable applicant is found, the job offer is closed, and its status is then set to position vacant.≪[6]

Generally, design-time entities are referred to a *type* and marked with a superscript T. Run-time entities are *instances* and are identified by a superscript I. In case no superscript I or T is given, the following definition for design-time and run-time entities applies. The dot (.) represents the access operator

2.2.1 Relational process structure

A object-aware business process is comprised of interacting objects. All objects in a object-aware process management are organised and structured in a relational process structure. In this structure, all objects are related. Additionally, user groups can be added, which can also be related to objects (e.g. Applicant and Application $1:n$). An relational process type structure records the object types (ω^T) and their relationship at design-time. Relationships can be $1:n$ or $n:n$. Formally an relational process type structure is defined as follows:

Definition 5. Relational Process Instance Structure [5]
A relational process instance structure d^I has the form (d^T, Ω^I, Π^I) where:

- d^T is the relational process type structure from which d^I has been instantiated
- Ω^I is the set of process instances ω^I (also called object instance)
- Π^I is the set of relation instances π^I

Definition 6. Object Instance [5]
A object instance ω^I has the form (ω^T, n, Φ^I, Θ^I) where:

- ω^T refers to the object type ω^T from which this object instance has been generated
- n is the name of the object instance
- $\Phi^I$is a set of attribute instances ϕ^I, where $\phi^I = (n, K, v_K)$, with n as the attribute instance name, K as the data type (e.g., String, Boolean, Integer), and v_K as the typed value of the attribute instance
- Θ^T is the lifecycle process (cf. Section 2.2.2) describing object behaviour

At run-time, an process instance ω^I (Definition 6) is instantiated from an process type ω^T. Each process instance ω can contain any number of attributes ϕ. For the attributes of a lifecycle additional conditions can be added. For example, the object *Job Offer* has the attribute *Publication Date*. The behaviour of an object is defined in a lifecycle (cf. Section 2.2.2). The relation instance π^I of Definition 7 describes the relation between the two objects ω^I_{source} and ω^I_{target}.

Definition 7. RELATION INSTANCE [5]
A relation instance π^I represents an $m : n$ relation and has the form (π^T, ω^I_{source}, ω^I_{source}) where:

- π^T is the relation type from which π^I has been instantiated
- ω^I_{source} in the source process instance, i.e., π^I is directed
- ω^I_{target} is the target process instance

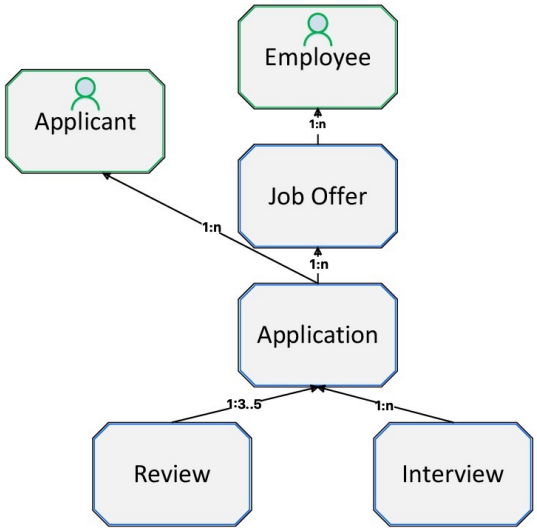


Figure 2.1: Relational process structure of the *Job Offer* process

Figure 2.1 shows a relational process structure d of the running example of the *Job Offer* process. In this case, four objects ω are given: *Job Offer*, *Application*, *Review* and *Interview*. There are also two user groups: *Applicant* and *Employee*. These user groups each have a $1:n$ relationship (π) to the objects *Job Offer* (relate to *Employee*) and *Application* (relate to *Applicant*). *Application* and *Review* have a $1:3..5$ relationship. Each *Application* requires at least three and at most five *Reviews*. All other relationships are $1:n$. For each of these objects,attributes can be defined. Each business process comprises several different objects and each of these objects has a lifecycle that determines how the object develops with its attributes over time.

2.2.2 Lifecycle

Lifecycles are one of the major components of an object-aware process management. They enable the execution behaviour of an object at run-time. In addition, forms are automatically generated from the lifecycles [4]. A lifecycle can be represented as a graph where each state is a vertex. Additionally, states contain steps (cf. Definition 8). In a more detailed view, these states can themselves be displayed as graphs where each step is a vertex.

In the following, a lifecycle process instance is specified. All grey marked properties are not relevant for this thesis but are nonetheless included. For the sake of completeness. Figure A.1 to A.4 in the appendix show the lifecycles of the four object instances of the relational process structure of the *Job Offer* process.

Definition 8. LIFECYCLE PROCESS INSTANCE: [4]
A lifecycle process instance θ^I has the form (ω^I, Σ^I, Γ^I, T^I, Ψ^I, E_θ, μ_θ) where

- ω^I refers to the object instance to which this lifecycle process belongs
- Σ^I is a set of state instances σ^I, with σ^I = (n, Γ^I_σ, T^I_σ, Ψ^I_σ, μ_σ) where
  - n is the state name
  - $\Gamma^I_\sigma \subset \Gamma^I$ is subset of steps γ^I
  - $T^I_\sigma \subset T^I$ is subset of transitions τ^I
  - Ψ^I_σ backwards transitions
  - μ_σ is the state marking
- Γ^I is a set of step instances γ^I, with γ^I = (ϕ^I, σ^I, T^I_{in}, T^I_{out}, P^I, λ, μ_λ, d_λ) where
  - $\phi^I \in \omega^I.\Phi^I$ is an optional reference to an attribute instance ϕ^I from Φ^I of object instance ω^I. Default is $\perp$. If $\omega^I = \perp$, the step is denoted as an empty step instance
  - $\sigma^I \in \Sigma^I$ is the state instance to which this step instance γ^I belongs
  - $T^I_{in} \subset T^I_\sigma$ is the set of incoming transition instances τ^I_{in}
  - $T^I_{out} \subset T^I_\sigma$ is the set of outgoing transition instances τ^I_{out}
  - P^I is a set of predicate step instances p^I, P^I may be empty, with p^I = (γ^I,λ) where
    - γ^I is a step instance
    - λ is an expression representing a decision option

    If $P^I \neq \emptyset$, the step instance γ^I is called a decision step instance
  - λ is an optional expression representing a computation

  - μ_λ is the step marking, indicating the execution status of γ^I
  - d_λ s the step data marking, indicating the status of ϕ^I
- T^I is a set of transition instances τ^I, with $\tau^I = (\gamma^I_{source}, \gamma^I_{target}, ext, p, \mu_\tau)$ where
  - $\gamma^I_{source} \in \Gamma$ is the source step instance
  - $\gamma^I_{target} \in \Gamma$ is the target step instance
  - $ext := \gamma^I_{source}.\sigma^I = \gamma^I_{target}.\sigma^I$ is a computed property, denoting the transition as external, i.e., it connects steps in different states
  - p is an integer signifying the priority of the transition
  - μ_τ is the transition marking

- Ψ^I backwards transition instances
- E^θ is the event storage for Θ^I
- μ^θ is the lifecycle process marking

A lifecycle θ^I includes states σ^I. This can be represented as a coherent acyclic (without consideration of the backwards transitions Ψ^I_σ) directed graph. The states represent the nodes and the transition represent the edges. Every lifecycle has exactly one start state and at least one end state. Between the start state and the end state can be any number of states. All states excluding the end state can contain branches. Thereby, non-linear lifecycles can be created. All states consist of steps. These steps of a single state again can be represented by a coherent, acyclic, and directed graph. To generate branching into a state, steps can be decision steps ($P^I \neq \emptyset$). In Figure 2.2, a partial lifecycle of the *Job Offer* is shown. The first state of this extract is the state named *Closed*. In this state, two steps are generated with the attributes *Closed Date* and *Applicant Found?*. The first step consists of a date. The second step defines a boolean attribute. The end user of this lifecycle can choose between *Yes* and *No*. By using such decision steps, branches can be generated in the graph of steps and states. In a lifecycle, only one state can be marked as *Activated*. Consequently, only one path can be executed. The remaining outgoing paths (transitions τ^I_{out}) in a decision step are skipped. For this reason, parallelism inside one lifecycle instance is not possible. Several lifecycle instances (from the same or different lifecycle types θ), however, can be executed in parallel.

The two remaining states, *Position Filled* and *Position Vacant*, of Figure 2.2 are the end states of a lifecycle. In a lifecycle at least one end state must be included. Since any number of decision steps can be included in a lifecycle, any larger number of end states can also be included. In the case of Figure 2.2 two end states exists. Formally, all end states must contain an empty step and only an empty step.

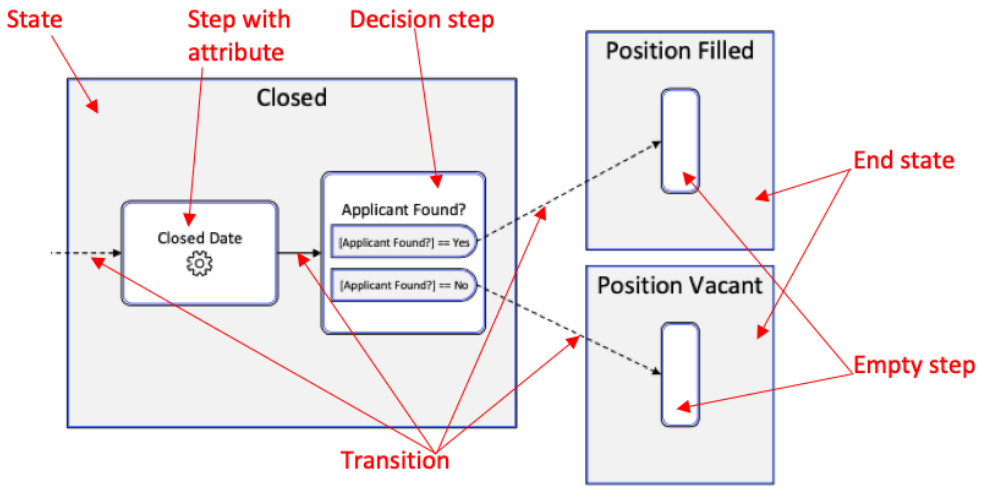


Figure 2.2: Extract of the lifecycle *Job Offer*. States: Closed, Position Filled, and Position Vacant.

States can be used as input for automatically generating forms. Figure 2.3 shows the state *Preparation* of the lifecycle *Job Offer* consisting of five steps. A form is generated automatically during run-time from the state. For the *Preparation* state of the *Job Offer* lifecycle the form shown in Figure 2.4 is generated.

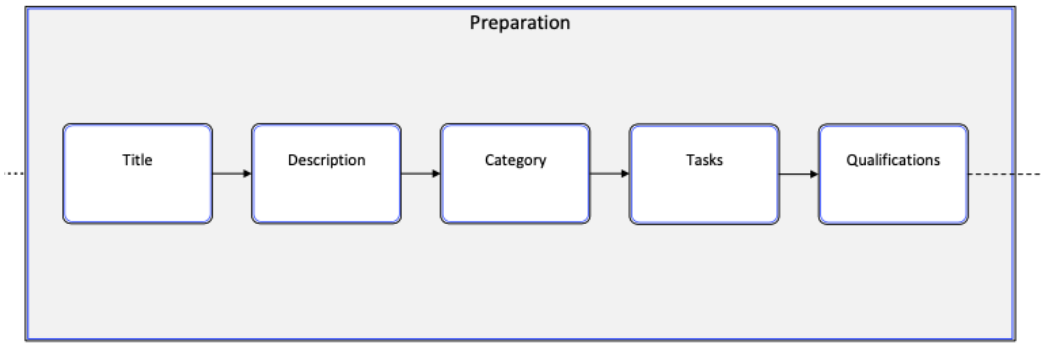


Figure 2.3: Extract of the lifecycle *Job Offer*. States: Preparation.

All attributes of a state are initialised in the object at the relational process structure. The data type is specified for each attribute of an object. Additionally, conditions can be

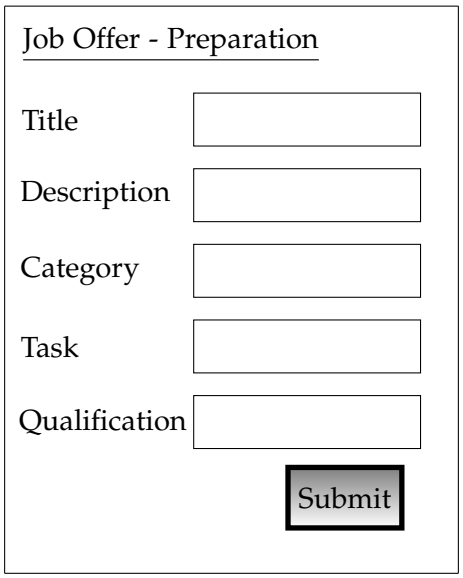


Figure 2.4: Form of the first state Preparation of the *Job Offer* lifecycle

defined for these data types. For example, a range of allowed values can be defined for an integer attribute.

Execution of lifecycle is realised with markings. This markings change according to process rules [4]. Thereby, the status of states, steps, and attributes is captured in markings. Of particular importance is the activated marking as it is currently the most relevant for process execution. The active marked state is used for the progress determination. All states before the active state have already been executed (corresponds to competed states). This completed states are marked as *Confirmed*. The numbers of completed states can be used to determine the progress in relation to the total number of execution states. Therefore, the active state describes the boundary between completed (actual progress) and pending (remaining progress to reach the 100 percent).

Each state generates a form as input for the data values. The displayed form is based on the active state. All states between the start state and an end state are executed in sequence. With a decision step the states are executed in sequence by the execution path (not parallel). When a path is eliminated by a decision step, all states of this path are marked as *Skipped*. Further, the marking *Waiting* exists. This marking describes a state that cannot be executed yet, because a predecessor state is marked as *Activated*. Each state can be coordinated in a coordination process. No matter whether a state is coordinated or not, the state can be executed in both cases. If the state is not coordinated, the marking is switch directly from *Waiting* to *Activated*. If the state is coordinated, it

still passes through the *Pending* marker. Here the activation of the state is blocked by an unfulfilled coordination constraint. This situation is defined with the marking is *Pending*. The order of the state markings is shown in Figure 2.5.

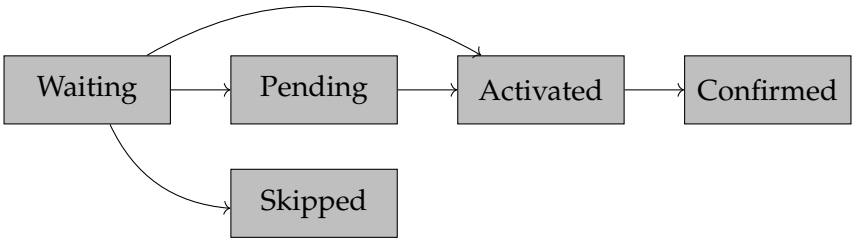


Figure 2.5: Possible order of markings μ_σ for a state

Furthermore, the markings of the steps are different from the markings of a state. Within the active state, steps and transition determine the order in which attribute values are required. A step with the marking *Enabled* functions analogously to an active state. This marking describes, which attribute requires a data value. When this data value is available, the step is marked as *Unconfirmed*. This marking describes, that the step possesses a valid data value. Steps within the active state are marked as *Ready*. This indicates, that they can become enabled in the future. Otherwise, if a step can no longer be executed, it is marked as *Bypassed*. The detailed semantics of state and step markings are much more complicated. A detailed list of markings used in lifecycle process execution can be found in the appendix (A.2 and A.2), together with a brief description. A more comprehensive description of markings and lifecycle process execution in general can be found in [6].

Lifecycles have a simplified representation through a state-based view. This is an abstract view of a lifecycle. This view corresponds to a lifecycle without steps (only a state view). Formally a state-based view is defined as follows.

Definition 9. STATE-BASED VIEW [6]
A state-based view θ has the form (ω, Σ, T, Ψ) where:

- ω refers to the object to which this state-based view belongs
- Σ is a set of states σ
- T is a set of transitions τ
- Ψ is a set of backwards transition types ψ

A state-based view θ is a directed, connected graph with a start state and at least one end state. All states σ are connected over transitions τ. Figure 2.6 shows an example of the a state-based view from the *Job Offer* object.

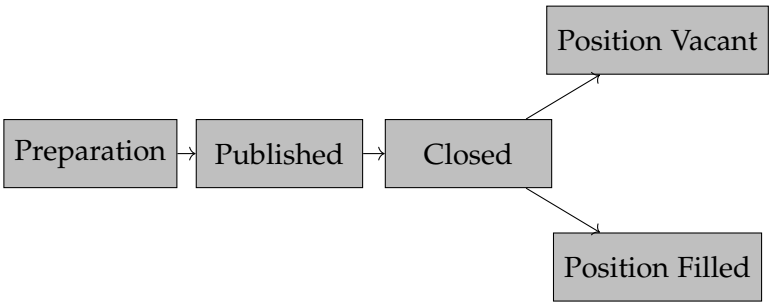


Figure 2.6: State-based view of the *Job Offer* object of the running example

2.3 Progress methods

There is no generally accepted definition of progress. This is based on the many disciplines of progress (e.g. philosophy, politics, technology and economics) and in each of these disciplines progress can be described using different metrics. All these disciplines described progress as a fundamental improvements through significant changes in existing conditions or processes. In literature, standstill and regression are described as the opposites of progress. To determine progress in a BPM system, several desirable metrics should apply. In addition, progress should not be assessed too positively. In project development, this is known as the 90 percent syndrome. This effect is caused by the already gained knowledge of possible solutions and at the same time ignorance of possible disturbances or impediments, which may still occur during the remaining 10 percent. In practice, this often results in an actual expenditure that is significantly higher than the apparently still required 10 percent [H13].

In general, there is no method or function that determines the real progress of a project or business process. Because real progress is not a number, but rather an inherently arbitrary measurement. Furthermore, there exists several definitions for calculating progress, which may produce different results. Therefore, there are no natural benchmarks to guide the quality of progress determination. Additionally, no statement can be made about the quality of the various definitions (apart from human intuition). For the real progress calculation, benchmarks must be defined first. These can be defined by objective statements. The idea is to define real progress as the union of all potential factors that can influence progress. With this idea statements about the determination of progress can be made. For example, 3 factors to calculate progress of an object-aware business process are worse than 9 factors. Real progress improves when a new factor is added to the calculation. Objectively viewed, more factors result in more realistic progress. An

overview of various methods from project management are introduced in the following. These are used as a comparison for the developed PPD-Method of this thesis.

Definition 10 introduces a method for progress measurement in which individual parts (e.g. milestones, activities, or work packages) of the process are considered to be atomic. These are either completed (100 percent) or not (0 percent). There are no intermediate steps. This Definition 10 is intended to prevent the estimation of the percentage of completion from giving a too positive indication of the progress of a project. The 0-100-Method is the most conservative method for assessing project progress. Further, this method is easy to implement, because no further measuring points and calculations are required. However, the 0-100-Method does not indicate the actual percentage of completion. Additionally, great jumps in progress are generated. The process progress only corresponds to the real progress in the start (0 percent) and end (100 percent) point. The greater the growth in progress, the greater the value of the progress is away from real progress. For example, the real progress determined 99 percent progress and the calculated progress with this method results 0 percent progress. This method is the opposite of the 90 percent syndrome.

> **Definition 10.** 0-100-Method [1]
> ≪The 0-100-Method is used to measure the progress of an activity or work package. An activity does not contribute to the percentage of completion as long as it has not been completed.≫

The 20-80-Method of Definition 11 is essentially a mitigated variant of the 0-100-Method. This method attempts to reduce the large gap between real and determined progress. Instead of allocatiy 0 percent progress at the beginning, 20 percent of the progress of an activity is allocated at the beginning. Additionally, this 20 percent must be calculated at the beginning. One disadvantage is that the mere start of a work package increases the percentage of completion. The jumps of this method generally have the same amplitude as in the 0-100-Method. With the completion of the current work package, 80 percent progress is assigned. When the current work package is finished, an additional 20 percent progress is assigned to the next work package. When all packages have the same size, the total progress is increased by 100 percent. The 20-80-Method is not an improvement of the measurement but only a statistical smoothing.

> **Definition 11.** 20-80-Method [1]
> ≪The 20-80-Method is used for simplified determination of the percentage of completion of activities and work packages. In this process, 20 percent of the costs budgeted for an activity are allocated to the earned value at the start of the activity. During the entire duration of the activity, however, the earned value does not increase. The remaining 80 percent of the budgeted costs are only credited to the earned value after the work result has been accepted.≫

The 20-80-Method as well as the 50-50-Method of Definition 12 introduced in the following mitigate the principle of the 0-100-Method and declare the percentage of completion at the start of an activity till the work package is actually completed at 20 percent and 50 percent respectively. Again the significance of the percentage of completion is limited.

The 50-50-Method is essentially a compromise between the 0-100-Method and the estimate of the percentage of completion. It involves the great danger that, for cosmetic reasons to improve the performance indexes, activities are declared as started although they are not yet actually processed.

> **Definition 12.** 50-50-Method [1]
> ≪The 50-50-Method is used for simplified determination of the percentage of completion of activities and work packages. In this case, 50 percent of the costs budgeted for an activity are allocated to the earned value at the start of the activity. During its entire duration, however, the earned value does not increase. The remaining 50 percent of the budgeted costs are only credited to the earned value after the work result has been accepted.≫

None of the described methods from software development is optimal. However, methods which determine the real progress are not easy to implement and require more computing capacity. Additionally, such methods have to be developed first since they do not exist yet. The description of progress and the defined methods for determining progress are needed in the following procedure of this thesis. From the description of progress some requirements for the determination and calculation of progress in a lifecycle in PHILharmonicFlows should be defined. Further, these methods are needed for a comparison and assessment with the developed PPD-Method.

2.4 V-Model

The V-Model is a process model for information technology development projects. The *V* stands for validation and verification. The special feature of the V-model is that it considers a development from a technical and functional point of view and defines quality assurance measures. In general, the V-Model minimises the project risks during the implementation of the project and reduces the total costs over the entire project and system [H14].

The V-Model is a procedure model, which is often used in software development. In Figure 2.7, the structure of the V-Model can be seen. The time is indicated on the x-axis of the V-Model. The level of detail is shown on the y-axis. The V-Model describes

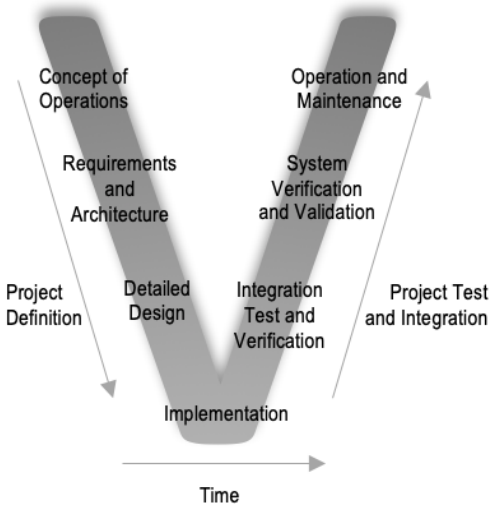


Figure 2.7: V-Model from software management project

three phases of software development. The first phase specifies the project definition and is represented with the first part of the letter V (falling line of the letter V). This phase includes: Concept of Operations, Requirements and Architecture, and Detailed Design. The second phase is represented with the bottom of the letter V and consists of the implementation of a project. The last phase of the V-Model is the Project Test and Integration phase, which is describes with the remaining part of the letter V (raising line of the letter V). This phase includes Operation and Maintenance, System Verification and Validation, and Integration Test and Verification. In addition to these development phases, the V-Model also defines the procedure for testing by comparing the individual development phases with test phases. The V-Model serves as a base line for discussion of the research question the methodology followed throughout this thesis.

3 Related Work

In recent years the use of business process management (BPM) tools has become more and more common and widespread. The number of these tools for processing BPM is increasing and these software are continuously improved. The usage of BPM tools allows the optimisation of processes, not only in large companies. An important aspect when using BPM tools is monitoring. This monitoring can be represented by various visualisations. In addition, the progress of a process can be measured and displayed in a BPM tool. Therefore, this Chapter gives an overview about the monitoring capabilities of different BPM tools and the visualisation of monitoring and progress in these BPM tools as well as examples of visualisations in other areas. Meanwhile hundreds of BPM software tools exist. For this reason, a selection must be made for a closer examination of the tools.

3.1 Business process management tools

In Figure 3.1, the individual logos of the three selected BPM tools can be viewed. The first selected BPM tool is AristaFlow [H1]. The logo of AristaFlow tool can be seen in Figure 3.1a. AristaFlow is a company from Ulm, Germany. The company of AristaFlow originated from a research project, which is carried out at the Institute for Databases and Information Systems at the Ulm University. The main reason of choosing AristaFlow: the software is provided free of charge for teaching and research and only sold commercially for businesses and industries. Many other BPM tools are not available free of charge for research and teaching. Others only have a 14-day trial version. Only free BPM tools are used for comparison.

The second selected BPM tool is Bonita software [H6]. The logo of Bonita software can be seen in Figure 3.1b. Bonita software originates from a research project from

France. The *Community version* is free for research and teaching. This version does not include support. In an online software catalogue from Capterra [H8] more than 400 BPM tools are listen. These more than 400 BPM tools are minimised by the following conditions: free version, rating with more than 4 stars, installation possibilities from Windows and Mac. Additionally the following functionality was assumed: Management for business policies, collaboration, process change tracking, process modelling & design. This minimisation left six BPM tools. Due to the positive evaluation and the insignificant described disadvantages (compared to the other six tools) this tool was included in the comparison.

(a) Logo of software tool from ARISTAFLOW [I3]

(b) Logo of software tool from BONITA SOFTWARE [I10]

(c) Logo of software tool from BIZAGI[I9]

Figure 3.1: The three selected BPM tools for further evaluation of their monitoring capabilities.

The last of the three selected BPM tool is [H5]. The logo of BIZAGI tool can seen in Figure 3.1c. The company's headquarters is located in Great Britain. The naming of this company is interesting, because it´s the composition of *business* and *agility*. The selection of BIZAGI is based on previous comparison from the trade press: A German weekly newspaper, namely *Computerwoche* (for CIOs and IT managers) wrote a report in 2015 about testing and evaluating 18 different BPM-Software-Suites [H3]. All 18 BPM-Software-Suites are reviewed and evaluated in terms of *overall evaluation*, *comfort* and *product capabilities*. The ratings of the different sectors would be expressed in percentages. With these percentages the following diagram from Figure 3.2 could be created. Of the 18 BPM tools BIZAGI has the best overall rating (and best *comfort* rating) and is therefore included in the comparison.

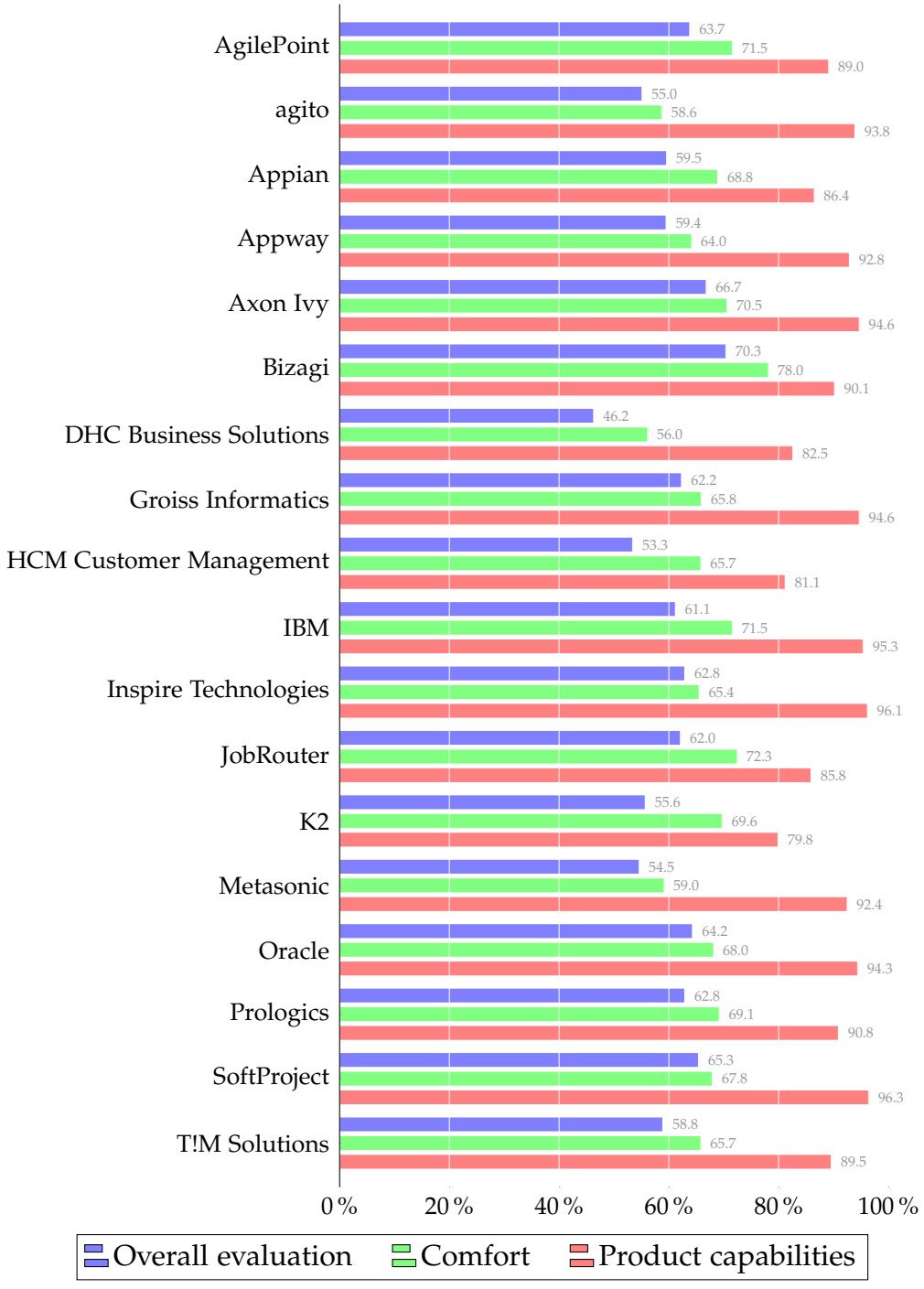


Figure 3.2: 18 different BPM-Software-Suites on review

3.2 Monitoring in BPM tools

This Section describes the monitoring capabilities and the progress calculation and determination of the three individual selected tools: AristaFlow, Bonita, and Bizagi. The emphasis is on the visualisation of the monitoring. First, the business process management software tools are compared in terms of monitoring and progress determination. Afterwards the graphical representation of the monitoring is evaluated.

3.2.1 AristaFlow

Monitoring in AristaFlow uses the graphical representation of the business process model. The current status can be monitored for each activity of the process model. A screenshot of the process monitoring is shown in Figure 3.3. The visualised business process model is shown in the centre of the UI. Each activity of an instance has a status. There are three different statuses: skipped, completed and activated. The statuses with their associated representation are listed in Table 3.1. In addition, the current status is colour-coded and assigned as follows: the status completed is shown in green, activated is shown in yellow and skipped is shown in red.

✗	Skipped
✓	Completed
▲	Activated

Table 3.1: Legend of execution statuses of AristaFlow

In addition to the colour coding of the BPM process, log data can be viewed in a table in the lower part of the UI (see in Figure 3.3). The log data is generated during execution of the BPM process itself. After the process is finished, a complete log data record is generated. The complete record can also be viewed in monitoring. The log data that can be viewed during execution includes: timestamp, state change, node name (activity name), node ID, iteration, agent ID and agent organisation position ID. The complete log data contains the same information as the log data, which is displayed during execution. They differ in the fact that the log data, which is represents in the UI during execution only contains the logs up to the current execution. The interactive process model and log data are the only information a user is presented in AristaFlow during and after execution.

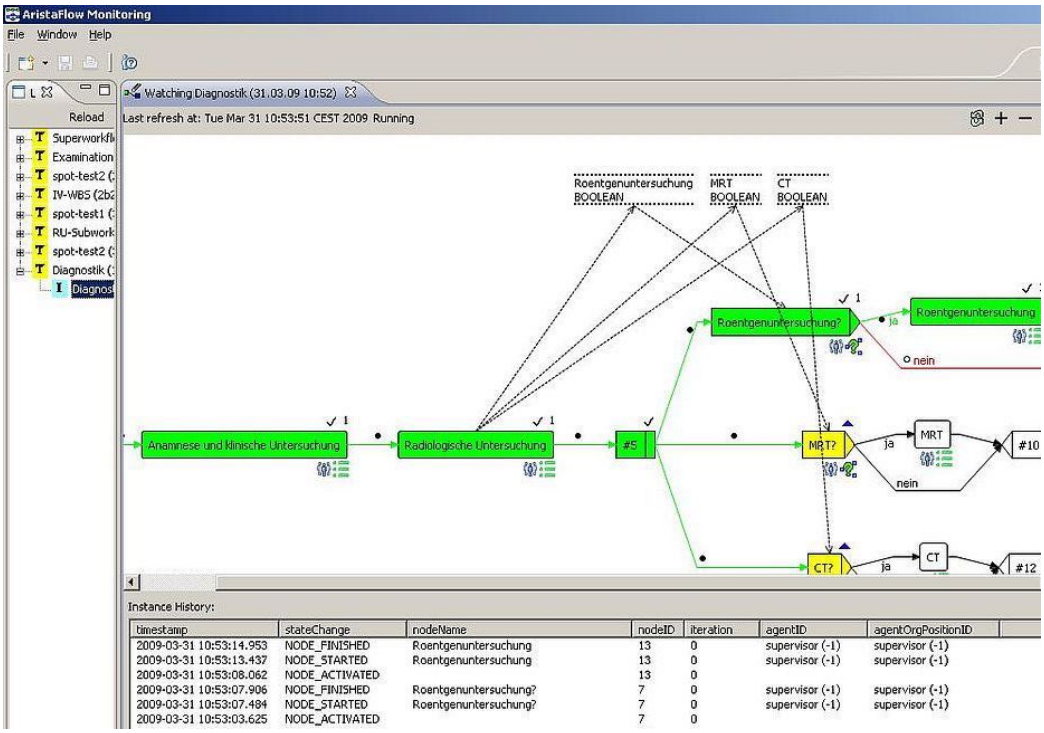


Figure 3.3: Monitoring tool from AristaFlow [I5]

In an interview with an employee of AristaFlow GmbH, the capabilities of the tool regarding the monitoring and the process progress could be discussed:
The process model can be monitored in real time. Changes in the workflow can be made during execution without running into errors. Furthermore, skipped activities can be analysed and observed. This enables authorised users to view, for example, the current status or the execution history of a process instance. It can be used to reset a currently failed activity or to make ad-hoc changes to a process instance. AristaFlow does not measure progress at instances in any way, e.g. with a progress bar. The first counterargument, the implementation is described as economically unviable. The second, user-specific monitoring (including the time of individual tasks/activities) might violate the personal rights of the employee (Article 2 paragraph 1 GG) and is therefore not considered. Despite these arguments against, an attempt to measure progress has been made. The Fluxicon Disco tool [H11] is used for this purpose. For this, the log data of a terminated process with associated instances is used as input for Fluxicon Disco. Progress determination in a business process is very complex. With the use of this tool no automated progress measurement can be obtained. Because of these restrictions, the approach is not pursued any further and no metrics describing the progress have been

defined. At the least, the process monitoring of AristaFlow can be used to determine when an activity starts and the duration of the subsequent activity. These two values can be used to determine how long an activity takes. However, this is not automated. An additional aspect of monitoring is documentation. All events in the audit trail can be logged. This means that processes that have already ended can also be reconstructed.

In summary, meaningful log data is recorded during the process execution. These can then be evaluated in a business intelligence analysis. The log data are displayed graphically during the process. These evaluations can then be found in the report. In AristaFlow **no progress calculation** exists. For this reason, progress calculation and determination can not be discussed and evaluated.

3.2.2 Bonita software

Bonita software is an open source platform for business process management and workflow applications. Bonita software consists of three main components that comprise the application. On the one hand, the data is managed separately in a database, called Bonita Continuous Delivery. On the other hand, the business logic that defines the processes can be displayed in Bonita Studio. Furthermore, the user interface can be designed with the Bonita UI Designer. In addition, Bonita software offers even more features. First, Bonita Portal is an out-of-the-box portal that enables end-users to manage tasks that are assigned to themselves. In addition, the owner of a business process can transfer sub-processes to participating end-users and manage them.

The *Community version* of Bonita Software only offers process monitoring via the Bonita Portal. The owner of the process can view the current status of the process (and the individual sub-processes) in a table. The business logic (in the editor), no parallel tracking of the current status can be viewed. In a report, all the activities that have been activated, cancelled and completed can be viewed graphically in form of a bar chart (similar to AristaFlow).

In Bonita Portal, the user can monitor a progress during execution. Here activities are referred to as cases. In Figure 3.4, the monitoring of Bonita Software in the Bonita portal can be seen. Additionally, Bonita Software has two types of metrics. Bonita-related metrics, which are enabled by default and cannot be disabled and technical metrics, which are disabled by default and can be enabled. Bonita-related metrics defines, for example, the number of currently running, pending, executed, or running connector works. Technical metrics defines, for example, several metrics related to worker or connector thread pools [H7]. The monitoring of the UI as shown in Figure 3.4 together with the log data is all available information regarding to the monitoring that is

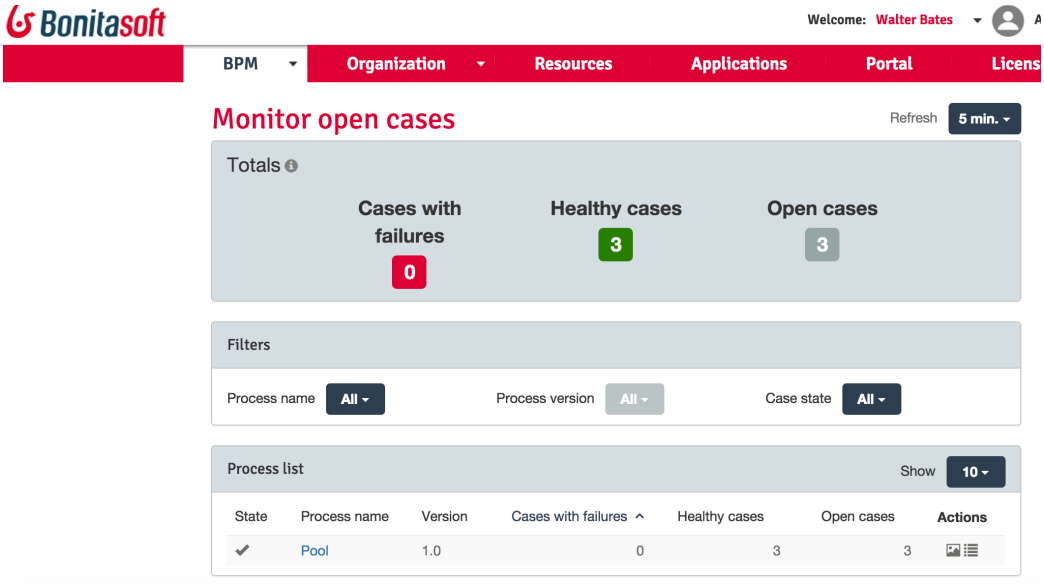


Figure 3.4: Monitoring tool from Bonita software

available in the Community version. In the Subscription version, the metrics can also be consumed via REST endpoint in the Prometheus format and graphical representation with tools like Grafana can be used to visualise the data. Similar to AristaFlow **no progress calculation** or representation exists in the Community version. Information about available progress calculation and determination in the Subscription version are not provided.

3.2.3 Bizagi

The monitoring of Bizagi is very extensive compared to other BPM tools. On the one hand, Bizagi provides monitoring of the underlying infrastructure and platform, that means the servers and other services integrated into the system, as well as monitoring the performance of the Bizagi services itself.

Bizagi uses its own diagnostic tool called Bizagi Diagnostics and has four main components: an ELK stack with LogStash for log transformation and loading Elastic-Search for memory and data operations and Grafana for data visualisation. Monitoring is provided by Bizagi under the term Business Activity Monitoring (BAM) [H4]. BAM is an analysis tool, which is used for graphical representation of the different cases (tasks and processes). The monitoring UI of Bizagi can be seen in Figure 3.5.

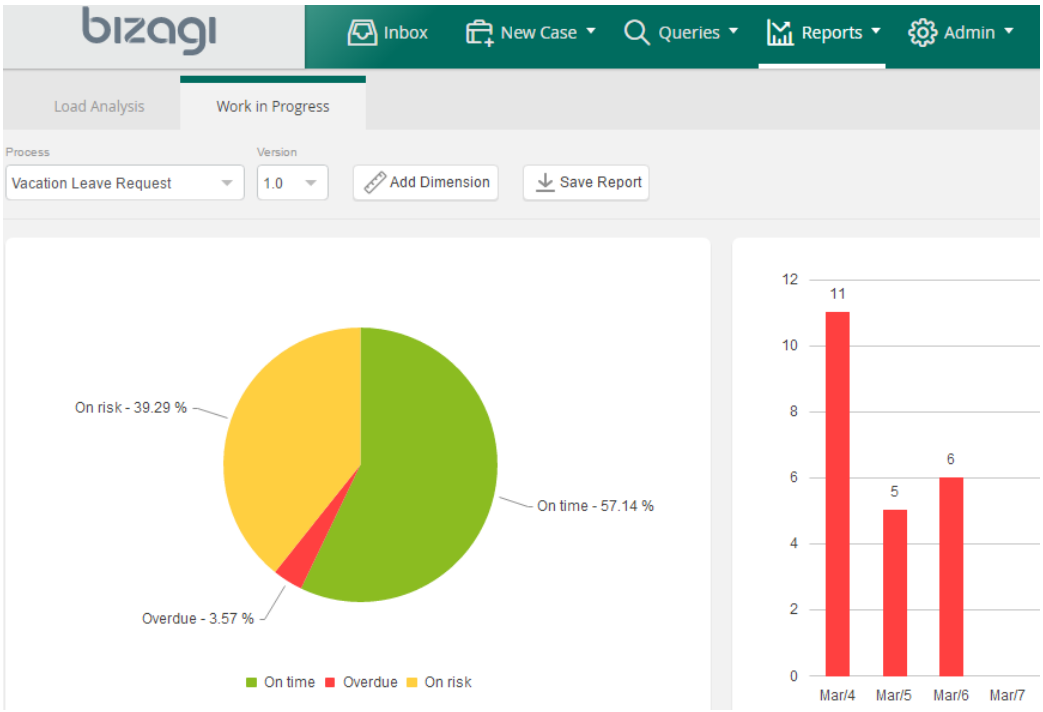
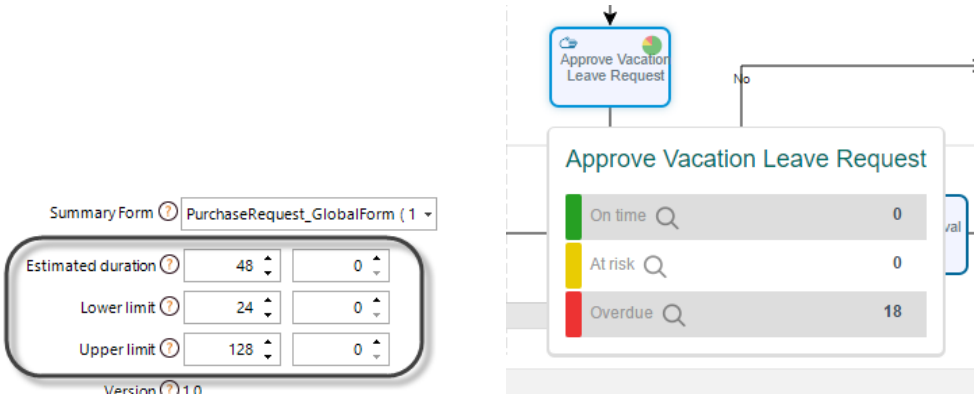


Figure 3.5: Monitoring UI of Bizagi [I7]

The monitoring of Bizagi offers a prediction about how many following activities are *overdue*, *on risk* or *on time*. Therefore, Bizagi offers a function for the process and task duration. To present monitoring and create reports, this function for determining the duration is used. This function must be configured for the use of BAM for each task. Figure 3.6a shows a part of a form for an task to configure BAM reports and monitoring. There, a lower and upper limit as well as an estimated duration (in *hh:mm*) of the task is needed to be set to enable prediction [I6].

Using these estimated values, a report about the current process can be created during run-time. In addition, various diagrams can be created which show the user the current status of a process. A pie chart can be created for each task, which specifies the expected execution time in a ranges of *on time*, *on risk*, or *overdue* of successor tasks. Thus, Bizagi can create a comparison between expected and actual execution. During run-time, a forecast can be created in the process model for each task or the entire process. Figure 3.6b shows the former possibility concerning a specific task. It is opened by clicking the pie diagram symbol of a task [I8]. For this task, a list of the three different categories including the amount of successor tasks in each category is shown. This is used as basis for a report (called BAM) that can be created at any given time for the entire process.



(a) Interface to set the estimated duration, the lower and the upper limit of an task [I6]

(b) List overview of an task in Bizagi [I8]

Figure 3.6: UI details of Bizagi monitoring

Each BAM report consists of three different parts. The first part Process BAM describes the analyses of the current state of all ongoing processes. The second part is the Task BAM. In comparison to the Process BAM, a single ongoing task is analysed. The third part is the Resources Monitor, which is used to analyse the current workload and performance of end users and work teams. These three report parts are generated by the monitoring of Bizagi. This monitoring capability and the resulting predictions are based on the manually provided information (lower and upper limit, estimated duration) about each task only. However, an **progress calculation and representation does not exist**.

3.2.4 Comparison

All three BPM tools have monitoring capabilities. Challenges which have been identified in the interview with an AristaFlow employee are probably also concerns the other tools. The main problem is the complexity of monitoring for many different autonomous processes. In addition, there are also data protection guidelines which must be followed. For AristaFlow and Bonita Software (Community version) no special and advanced monitoring exists. The only information provided is where the process is at time T and who has made which changes. Furthermore, log data can be created. Due to the fact that the Bonita software in the Subscription version is commercial and is not available for this thesis, no statement can be made about this version with regard to monitoring. However, the Subscription version has differences to the Community version in terms of monitoring functionality [H7]. For example, the Subscription version provides additional

monitoring functionality via REST Endpoint and Grafana, similar to Bizagi. All three evaluated tools allow real-time monitoring of running business processes. Changes to the current business process can be made in all tools during execution. In addition, diagrams are created automatically during run-time. The process activity histogram compares open, closed, and cancelled activities/cases/tasks over a period of time. The trend diagram shows the trend of activities/cases/tasks creation over a certain period of time. Furthermore, different metrics are defined in Bonita Software and Bizagi. But non for progress monitoring. Another disadvantage of Bonita Software, it does not offer monitoring in the Community version. Only a list of open and closed processes. AristaFlow has no metrics defined at all.

	AristaFlow	Bonita Software	Bizagi
BPMN-Diagram (colour coded)	✓	✗	✓
Table of current actions	✓	✓	✓
Automatic report creation	✓	✓	✓
User specific view on tasks	(✓)	✓	✓
Predictions about the course of the process	✗	✗	✓
Progress view	✗	✗	✗

Table 3.2: Summary and comparison of the monitoring capabilities of: AristaFlow, Bonita Software, and Bizagi

In comparison, Bizagi offers more, clearer and illustrative information than the other two BPM tools, AristaFlow and Bonita Software. This difference can be seen in the individual UI Figures 3.3, 3.4 and 3.5 and in the Table 3.2, which gives a summary of monitoring for all three tools. AristaFlow and Bizagi can visualise the modelled process in a BPM-Diagram with colour encoded states for each activity or task. For example, AristaFlow encodes completed activities in green, activated in yellow and skipped in red as shown in Figure 3.7. Created log data of a process during run-time can be view in a table in AristaFlow. Additionally, a report is created at the end of the process in all three BPM tools. However, these reports differ in quality. For example, Bizagi generate a more detailed and graphically illustrated (with diagrams) report. Additionally, it is possible in Bizagi to create a report during run-time. Bonita Software and Bizagi provide an external user portal. Each user is shown her tasks or cases directly. In contrast, AristaFlow does not provide an additional portal but only a work list. Predictions about the duration of the process exists only in Bizagi. This is only based on manual user input as shown in Figure 3.6. Bizagi provides a graphical evaluation of the individual activities

with regard to *overdue*, *on risk* and *on time*. Progress calculation and determination exist in non of these tools.

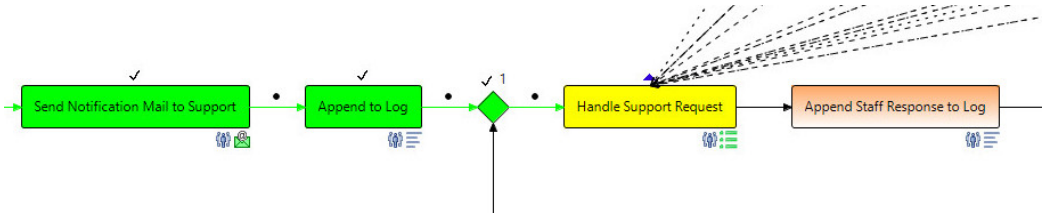


Figure 3.7: Example AristaFlow Monitoring: completed (green), activated (yellow), skipped (red) and untouched (orange) [I4]

3.3 Progress measurement and visualisation

An important part of monitoring is the progress analysis. Progress is visible in the form of diagrams, for example, bars or pie charts, a percentage display or by colour encoding in the business process. All considered business process modelling tools use, inter alia, the form of the encoded colour scheme in the running business process model. An example of AristaFlow monitoring is shown in Figure 3.7. Furthermore, the status of an activity and thus the progress of the process can be viewed in the form of a table. The contents of the table are almost identical in all considered business process modelling software tools. In addition to the state of the activity, supplementary time stamps, incoming and outgoing nodes of the next activity and roles can also be assigned.

The larger the business model, the more confusing the overall overview of progress analysis and monitoring becomes. Therefore, research is currently underway on how monitoring can be made more user-friendly in the domain of progress analysis and measurement. The progress analysis is not included in any of the business process tools previously analysed. A graphic or textual representation of the total duration or the current progress is not available. Therefore, progress determination outside of business process tools should be viewed.

3.3.1 Gantt chart

A GANTT chart is often used in project management, because it is one of the most effective methods for displaying activities in relation to time. GANTT diagrams are also used in operations management as production planning and control instrument [H12].

The GANTT diagram can be found in many planning or preparation scenarios. Apart from the conventional areas of application also in management environments.

Figure 3.8 shows an example of a GANTT chart. To create a GANTT chart the following information about the project or process is needed:

i. Which different activities are there
ii. When each activity starts and ends
iii. Which duration is planned for each activity
iv. Where activities overlap and for how long
v. Start and end date of the entire project

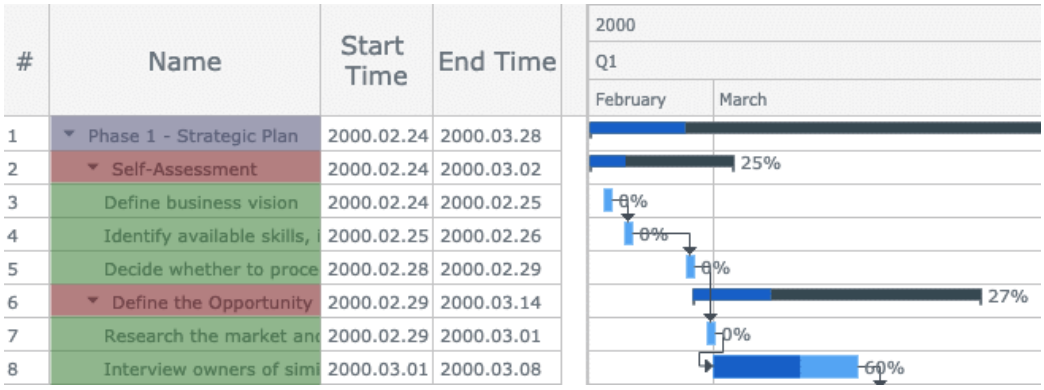


Figure 3.8: Example of a GANTT chart [I1]

Before GANTT charts are designed with a computer or software tool, the information (i.)-(v.) about the project were even more important. With every subsequent change in the GANTT chart, a new one had to be created. For this reason, the popularity of this diagram increased with the spread of computers and corresponding software tools. With the use of a software tool, changes can also be easily integrated during the project phase. The difficulty lies no longer in the adjustment in the GANTT chart, but *only* in the planning implementation of the project. Before the support of modern software tools,

GANTT charts are primarily used for documentation. Today, it is more common to be used during the planning phase.

To explain how a GANTT chart works, Figure 3.8 is considered again. On the left side of Figure 3.8, a table with the provided data can be viewed. In addition to the activities, this includes their associated start and end dates. Furthermore, the activities are sorted by time and grouped by phase. On the right side of Figure 3.8, the GANTT chart can be viewed depending on the time. There are different activities for each phase. For example, *Phase 1 Strategic Plan* (purple marked) has two activities (red marked): *Self-Assessment* and *Define the Opportunity*. For these activities some sub-activities (green marked) exist. The GANTT chart on the right side visualises each activity with its corresponding duration (width of the bar, marked as blue bar), its time of schedule (horizontal position of the bar) and its current process (percentage on the right of each bar). Furthermore, it shows the predecessors (incoming arrows) and the successors (outgoing arrows) for each activity [H12].

One of the the advantage of a GANTT chart is clarity. Since a GANTT chart presents different activities and timelines in their entirety, it provides a good and clear overview for all involved persons. In this way, everyone involved can see in which phase the project is at the moment, which resources are needed and how certain activities are distributed. This can provide an exact overview of the current status of the project and an estimation whether it is successfully completed in time. A second advantage is communication. A team in a project can use GANTT charts to reduce the number of meetings. Additionally, the project status can be updated quickly. This provides a well-organised view of the progress of each task. Another advantage is motivation. It has been shown that a clearly defined overview increases motivation and thus the overall performance of the project. Another aspect of this is that correlations between activities are explained. This way, it is visible to everyone what the delay of individual activities means for the whole project. This encourages cooperation and better coordination of activities. An additional advantage is time management. The bars in the diagram indicate a time period in which a certain activity should be completed. This ensures that other projects are not missed out because too much time and resources are used on another project or activity. In addition, GANTT charts are flexible and can be adapted. Due to the unexpected and often numerous changes in the project during the implementation, activities and resources (thanks to the good overview) can be easily (even if time consuming) modified. A final advantage may be that overlaps and conflicts can be quickly detected graphically by using the GANTT chart [H2].

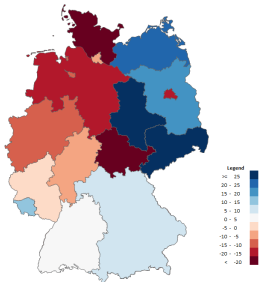
On the other hand, some disadvantages exists. The first one is complexity. This increases with the numerous activities and resources. This is especially the case when it is a large project or the responsible team has a lot of employees. This can make the GANTT chart very extensive and difficult to understand. A second disadvantage is the linearity.

This means that a project must be represented in linear from start to finish to enable a successful GANTT chart. This includes that at the start of the project there must be an idea of the end result. Additionally, all necessary intermediate steps must be known. This is especially difficult if no specific end result has been defined by the client in the first place. A further disadvantage is workload. To initially design a GANTT chart in a meaningful way a lot of effort is needed. Changes that occur during the course of a project can also take a lot of effort [H2].

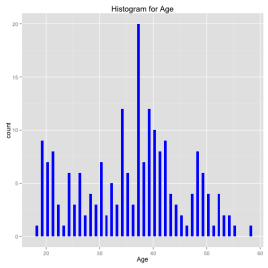
3.3.2 Types of visualisation possibilities and diagrams for progress

The most common diagrams [H9] can be viewed in Figure 3.9. For each of the diagrams in Figure 3.9, there are several sub-types of them. Before evaluating each specific sub-types for all diagram types, some can be excluded from the outset. This is because the use case *progress measurement in business processes* cannot be represented with these diagram types.

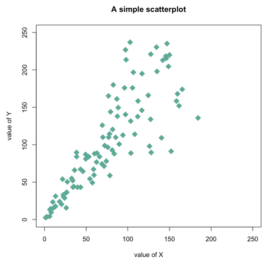
In Figure 3.9a, the diagram type cartogram [I11] can be seen. This type of chart is ideal for viewing information in connection with different regions. Of course, this information can also be progress towards a defined goal in comparison to different countries. However, the reference should always be to countries or regions and not to a specific business process. For this reason, a closer look at the sub-categories of such a diagram is not necessary.
The second diagram in Figure 3.9b represents a histogram [I12]. These are typically used for graphical representation of the frequency distribution of measured values. Again, it is difficult to use this type of diagram to achieve a meaningful representation of the progress measurement. It is therefore dismissed.
The next diagram type is the scatterplot [I14] (or dot diagram) as shown in Figure 3.9c. Scatterplots are excellent for showing the relationship between variables and thus also for demonstrating regression and correlation. Considering progress measurement, a second variable is needed to create such a diagram. For example, progress can be put in relation to time. However, this does not produce a progress diagram from which the current progress of a business process can easily be read. The diagram can be used to subsequently determine how long a business process took to run in relation to different conditions. It follows that this diagram type is not used for further evaluation.
A box plot [I15] as shown in Figure 3.9d is a summary of a data set of five points. These five points are the minimum, the lower quartile (25th percentile), the median (50-th percentile), the upper quartile (75th percentile) and the maximum. In a box plot, a box is drawn between the lower and upper quartiles. A vertical line crosses the box at the position of the median. The whiskers connect the two quartiles represent the minimum



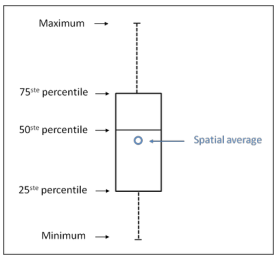
(a) Cartogram [I11]



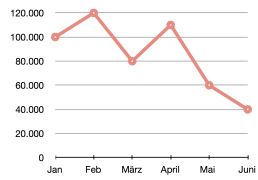
(b) Histograms [I12]



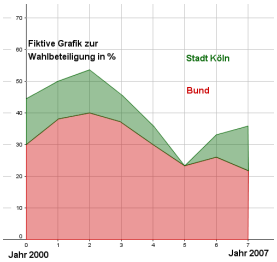
(c) Scatterplot [I14]



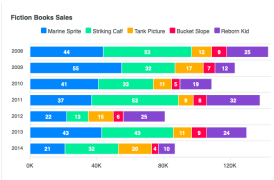
(d) Box plots [I15]



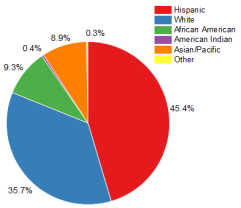
(e) Line charts [I16]



(f) Area diagrams [I20]



(g) Bar charts [I2]

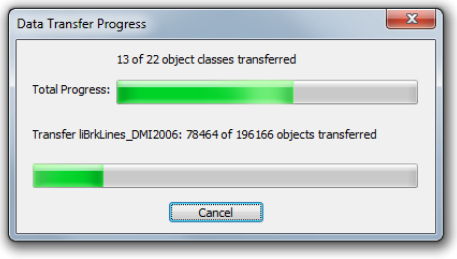


(h) Pie charts [I18]

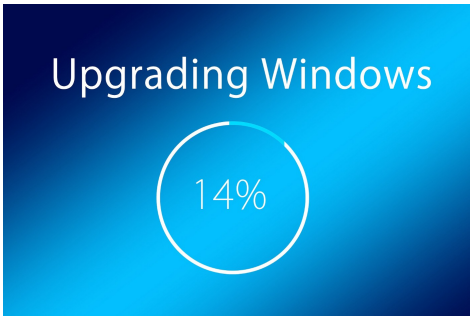
Figure 3.9: Different diagrams illustrating graphical data.

and maximum, see Figure 3.9d. This diagram type is not suitable as a progress indicator as it mainly shows the distribution of values for a single variable.
Figure 3.9e shows a line chart [I16]. These are particularly suitable for the representation of developments. For example, to visualise the development of the number of the population over time. For this reason, the line diagram is not suitable to visualise progress.
An area chart [I20], see Figure 3.9f, is basically a line chart with the area below the line filled in. As well as the line chart, this diagram type is also not suitable to represent progress.

In Figure 3.9g, a bar chart [I2] is shown. In relation to measuring progress, this type of diagram in the form of one bar can be used as a progress bar. An often used progress bar [I13] can be seen in Figure 3.10a, when copying data on a computer. The upper bar of Figure 3.10a shows the progress (13 of 22 objects classes transferred) of the total transfer process. The lower bar shows the transfer progress (78464 of 196166 objects) of the 14th object. There are different sub-types of bar charts. A classic bar chart is shown in Figure 3.10a. A more advanced bar chart can be seen in Figure 3.9g and is called stacked bar charts. A use case for stacked charts can be to compare the distribution of the same variable in different samples/populations. For example, the amount of followers of different religions for individual countries. Another sub-type of bar chart is the GANTT chart described in Chapter 3.3.1. The stacked bar chart and the GANTT chart can be used as a progress chart where each bar (or sub-bar) represents an activity of a business process. However, in the software tools for creating business processes analysed in Chapter 3.2, these types of diagrams are not used for progress analysis.



(a) Progress bar of data transfer [I13]



(b) Progress pie of upgrading Windows [I17]

Figure 3.10: Known progress bars

The last diagram type is the pie chart [I18], see Figure 3.9h. This can plot the percentage for various variables. A known use case of a progress pie diagram is the Windows update [I17], shown in Figure 3.10b. Here, the current progress for the Windows update is shown

in real time (light blue finished part and white still missing update part). The division of a pie chart is equal to the stacking bar chart. They differ in the presentation. Such a diagram is also used to evaluate and monitor business processes.

3.3.3 Sunburst

In this Section, a sub-type of a pie chart diagram is introduced. This diagram type is called sunburst. It is used, for example, by the company Paessler AG in their own monitoring of networks as shown in Figure 3.11. This diagram may be used to represent the progress of lifecycles in an object-aware buisness process.

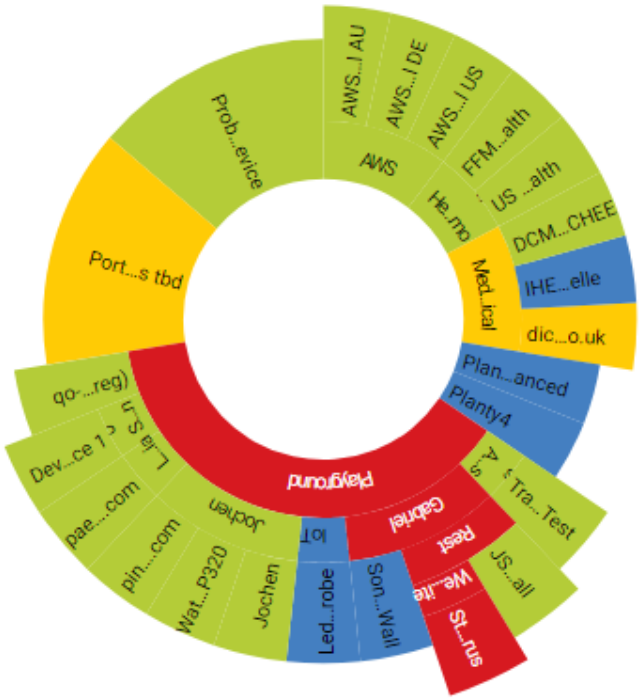


Figure 3.11: Network monitoring diagram: Sunburst from a PRTG network monitoring [I19]

The company Paessler AG offers bandwidth monitoring and the PRTG (Paessler Router Traffic Grapher) network monitor, a commercial network monitoring software. Monitoring can include routers, switches, servers, hardware, software, OS, applications,

virtual environments, web pages, email servers, databases, temperature, humidity and much more, corresponding sensors required. A sensor is used to define a measuring point that monitors a certain aspect of a device. For example, the CPU load of a computer can be monitored. For all this, PRTG can generate daily, weekly, monthly and annual reports for defined sensors.

Part of PRTG's monitoring is represented by sunburst diagrams. The main components are located in the inner ring of the pie chart (sunburst). Each of these components can be expanded. This creates the *sun rays* of the sunburst and can be seen in Figure 3.11. The various colours encode the different states of the individual sensors. For example, an error in a network that is detected by a sensor is highlighted in red in the diagram. An advantage of this diagram type is that a sensor in alarm mode (marked red) transmits this signal to its inner ring. In Figure 3.11, one component of the outermost ring (marked red) triggered an alarm. The alarm is handed over the signal to all involved components in its inner ring. This means that if a network has several sub-networks, the alarm is displayed in the innermost ring. These sub-networks can in turn be further divided. The smallest component on the outermost ring is a sensor. If a sensor alarm is triggered, the corresponding colour coding is adapted in all higher-level parts of the system, see in Figure 3.11 red part. This makes it easy to find out which components have issues [H10].

The visualisation of the monitoring used by Paessler AG can be transferred to represent the progress of an object-aware process management like PHILharmonicFlows. In an object-aware business process, lifecycles can be ordered by their relationship of the relation process structure. Thus the sunburst diagram type offers a promising basis for a clearer and more comprehensive visualisation of process progress in BPM Tools.

4 Research Questions

Developing the PPD-Method for an object-aware business process requires a unique and realisable solution. In general, there are several ways to design this PPD-Method. The main focus of this Chapter is to discuss all possibilities and develop a method, which determines the progress of a lifecycle process instances.

4.1 Research Context

Determining progress of an object-aware business process comprises many challenges and several possibilities. On the one hand, in object-aware determination of progress suitable measurable units must be defined. Quantitative benchmarks need to be identified to measure progress. In an object-aware business process, another challenge is the time-delayed identification of goal fulfilment. The behaviour of an object is specified by the existing and defined possibilities for an object during run-time. In an object-aware business process, the behaviour of an object is described by its lifecycle. Several possibilities how a lifecycle is executed exists. The outcome is not known beforehand. In contrast to project management, where the goal is known from the beginning. Therefor, the outcome of an lifecycle must be estimated correctly. Further, to determine the progress by comparing actual execution point with the goal of the object. In addition to these challenges, the effort for each measurable units must be estimated. Looking at progress by work, a determination of the workload for each measurable units must be made. If progress is defined in terms of time, the time required for each measurable units must be estimated. A further challenge is the determination of the remaining expenditure of a measurable units at run-time. The behaviour of an object in an object-aware business process is determined by its lifecycles. These lifecycles have various types of dependencies with each other. At run-time, a lifecycle process instance is generated

for each object instance. These lifecycle process instances can be executed in parallel. For a given business process, progress should be determined and presented. For the first consideration, progress should be shown in a bar chart called a progress bar. This progress bar shows a progress from 0 to 100 percent.

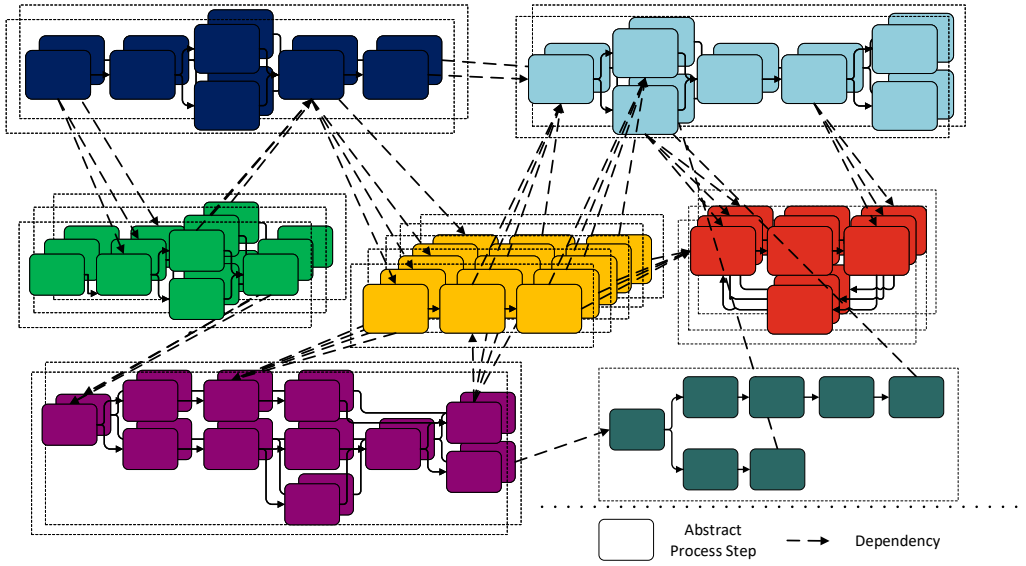


Figure 4.1: Big picture: Process Dependency Structure of process lifecycle instances [5]

The complexity of an object-aware business process can be seen in Figure 4.1. In this Example, there are seven different lifecycles. In general, there are many different process instances, which are instantiated from many different types. The process instances consist of a sequence of states. Additionally, the execution of a state in one lifecycle depends on states in other lifecycles. This creates an additional complex structure of dependencies. For the PPD-Method of an object-aware business process, research questions are defined to discuss the problems of this determination. With the divide-and-conquer principle the problem of the determination is split up in the following research questions. Further, these research questions can again be divided in sub-research questions.

Research question 1. How can progress of a lifecycle process in its state-based view form be determined?

Research question 2. How can progress within a state of a lifecycle be measured?

Research question 3. How can the progress of multiple, different lifecycles with relations be determined?

Research question 4. How does a coordination process affect the progress of an object-aware business process?

Research question 1 considers lifecycle processes in their simplified state-based view. Research question 2 considers intra-state progress to refine Research question 1. Research question 1 and 2 together fully determine progress of an individual lifecycle process instance. Every single lifecycle from Figure 4.1 can be assigned a progress between 0 and 100 with the result of Research question 1 and 2. Research question 3 extends this to a full relational process structure. Multiple lifecycles process instances of the same and different objects are combined together and an overall progress is determined. Research question 4 considers coordination (in Figure 4.1 represented by the dashed arrows) of the relational process structure to refine Research question 3. With Research question 4 the total progress of a business process is considered. The results of these research questions defines the PPD-Method.

In addition to the step-by-step determination of the PPD-Method, a further simplification of the complexity is made.

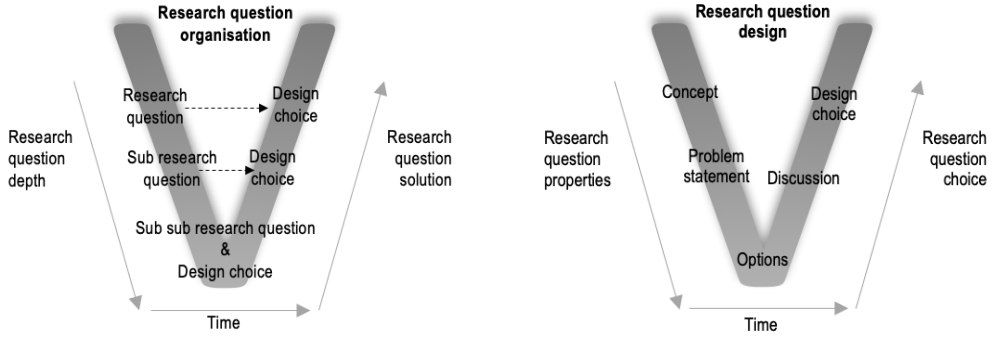
Therefore, the PPD-Method uses a fixed snapshot of an object-aware business process, taken during execution, to determine progress. This is called static determination and reduces the complexity of the calculation. This snapshot sets the basis for the consideration of the dynamic aspects and can be incorporated onto the progress determination, such as instantiation of objects or deletion of objects. In the running Example of the *Job Offer* process applications can be sent (create an object instance *Application*) or withdrawn (delete an object instance *Application*).

4.2 Research Focus

The focus of this thesis is on the discussion of Research question 1 and 2. With the first research question the progress of any lifecycles process instance in a state-based view is determined. For the described challenges from Section 4.1 solutions are discussed and determined. Sub-research questions are discussed to determine progress in a state-based view. The structure of this discussion is described in the following Section. The progress determination is refined with the second research question. The active state of lifecycle are considered in detail to refine the current progress of a lifecycle process instance. In this second research question, the progress determination for any intra-state of a lifecycle is discussed. The goal of this thesis is to define the PPD-Method to determine the current progress for any lifecycle process instance in a static context.

4.2.1 Methodology: V-Model and design choices

The idea of the V-Model can be refactored into two new models to solve the research questions of this thesis. The first converted V-Model is used for the organisation of the individual nested research questions and can be viewed in Figure 4.2a. This structure is beneficial for structuring the various research questions. Often the solution for the research questions cannot be found directly. For this reason, sub-research questions are introduced. In some cases, sub-research questions are used to answer the original research question. This V-Model describes the organisation of the various research questions.



(a) Organisation of research questions based on the V-Model

(b) Form of each individual research question based on the V-Model

Figure 4.2: V-Models: Structure of complex research question

Figure 4.2b shows the second generated V-Model. This V-Model describes the methodology to solve an individual research question. This form can be used for research questions, sub-research questions, and sub-sub-research questions. The structure to answer these individual research question is a V-Model. The first part of the V-Model (falling line of the letter V) describes the properties of a research question. This includes the problem statement and the context of the research question. The second part (bottom of the letter V) shows all various option to solve the research question. The last phase of the research questions (raising line of the letter V) consists of the choice to answer the research question. This includes the discussion about all option with their advantages and disadvantages. Mostly, there exist more possibilities to answered the research question. For this reason, the best option for the describe context is taken. The selected options (or the combination of the various options) are defined in a design choice. With the choice from the various options this discussed research question is completed.

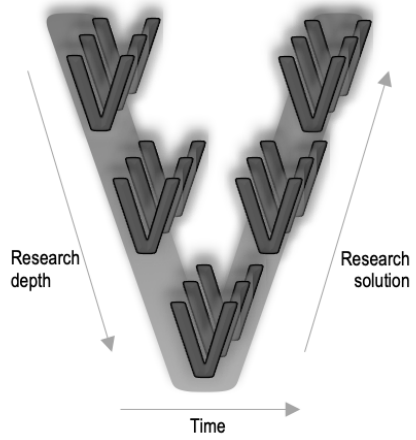


Figure 4.3: Nested V-Model

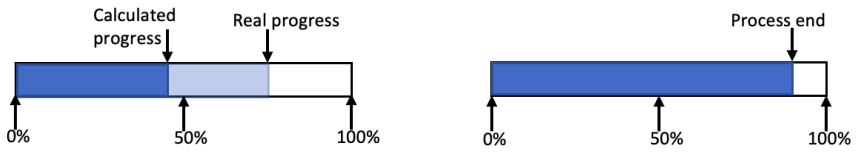
In Figure 4.3, the V-Models from Figure 4.2 are combined in one nested V-Model to represent the approach of the discussion for research analysis and design of the PPD-Method. The big V of the Figure represents the organisation of a research questions with their sub-research questions (cf. Figure 4.2a). And the small Vs of Figure 4.3 represents the form of each individual research question (cf. Figure 4.2b). Each of the four defined Research question 1 to 4 can discussed with this nested V-Model.

4.2.2 Requirements

The most important requirement for online monitoring is to calculate and determine progress in real-time. This problem statement of calculated progress in real-time can viewed in Figure 4.4a. The calculated process is less than the real progress is. This condition is considered in the first Requirement 1. A progress calculation during run-time, that cannot be performed in real-time (only with large time delay) is useless.

> **Requirement 1.** *Real-time calculation*
> For firm real-time monitoring, the corresponding calculation for determining progress must also be performed in real-time.

In real time systems, a distinction is made between hard, soft and firm real time. For an exact Requirement 1 this distinction must be considered in order to choose one of these types of real-time.



(a) Real-time calculation **(b)** Exploit progress bar completely

Figure 4.4: Requirements of a progress bar

- **Hard real-time requirements**: In hard real-time systems a precise upper limit for the response time for each task is defined. Exceeding the response time is considered a failure. Real-time systems must always deliver the correct result within the given time limits, because exceeding the time limits for the response can have substantial consequences. For example, the airbag trigger in a car must trigger within 30 milliseconds to protect the passenger. To calculate and enable such prerequisite, calculations according to the theory of real-time systems are necessary.
- **Soft real-time requirements**: Such systems typically process all incoming inputs fast enough. For example, the response time reaches an acceptable average value or another statistical criterion. The time requirements should be seen as guidelines here. Exceeding the time requirement does not have to be considered a failure. On the one hand, the time can often be slightly exceeded as long as it is still within a tolerance range. On the other hand, it can rarely be significantly exceeded.
- **Firm real-time requirements**: For firmed real-time requirements there is no immediate threat of damage by not meeting the upper limit for the response time. However, once the time requirements are exceeded, the result of the calculation is useless and can be discarded [7].

There is no danger or risk for the progress determination if the calculations cannot take place in real time. Any potential danger results from the delayed progress but not from the delayed determination of corresponding progress. The monitoring area is used to monitor the progress of a process. When the progress of a process is less advanced than the actual progress, the output of the progress is useless but does not result in any direct danger. For this reason, monitoring is not considered to be hard real-time. Soft real-time is also not the best choice because the average is not meaningful for monitoring. Once a very good calculation time is delivered and otherwise always minimally too late, this real-time would be successful, in case of monitoring it is not successful. Therefor, the definition of firm real-time applies the most for monitoring purposes. At best the result

are none to only slightly distorted and the quality of the monitoring is sufficient. At worst, the result are useless due to a delay during the calculation.

For the calculations of the progress in percent and the following graphical representation in a progress bar, the following requirement is essential. The progress calculation of a lifecycle should be utilising the percentage scale from 0 percent up to and including 100 percent in its entire range. All progress bars shown should have the same interpretation of 100 percent (and all possible percentage between 0 and 100). A lifecycle not reaching the 100 percent when terminated (for example only 60 percent) results in the following calculation of the overall progress determination being inconsistent. When the total progress is viewed over the average of all individual lifecycle process instances, the 100 percent can never be reached, because one lifecycle process instance was terminated at 60 percent. A different interpretation of 0 percent will also produce an incorrect result. In addition, a progress bar should be predictable for an end-user. For example, if the progress bar shows 90 percent done at the time of the instantiation of a lifecycle process instance, that means progress start at the 90 percent mark of the progress bar. Such a progress bar leads to misinterpretations and does not meet the intuitive expectations of a user. It is expected from monitoring that both 0 and 100 percent can be calculated and graphically displayed in a progress bar. With Requirement 2 the utilisation of the progress bar are defined to not counteract the intuitive expectations of end-users as good as possible.

> **Requirement 2.** *Full progress bar utilisation*
> The percentage possibilities from 0 to 100 percent must be entirely utilised during execution. For the graphical representation in a progress bar all areas can be displayed.

An example where this requirement is not satisfied can be seen in Figure 4.4b. In this example, the process terminated before the 100 percent were reached. In this case, 100 percent is never arose. Additionally, the 0 percent should also be part of the progress bar. At the start of the process, the calculated percentage should not be greater than 0 percent. The value should be exactly 0 percent.

In the Research question 1 at a state-based view the progress determination considered states as the atomic unit and in the Research question 2 steps are used as the atomic unit. For this, all states are assigned the same percentage to. Thereby, no bigger jumps as the assigned percentage is occur.

> **Requirement 3.** *Uniform progress*
> Any increase in progress must be proportional to the change it represents. Otherwise, increments in progress should be of the same size if possible i.e progress should not make big jumps outer changes are big as well.

For example, a lifecycle with 6 states like in Figure 4.5 is given. After the execution of the first state the progress is determined with 50 percent. This is based on the distribution resulting from executing the shorter path.

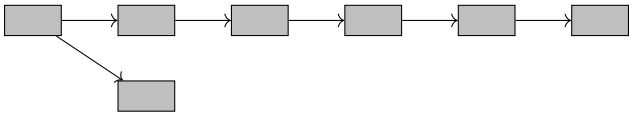


Figure 4.5: Lifecycle with 2 paths

However, the remaining states of the longer path are represented by the remaining 50 percent. In this case, each of these 5 states stands for only 10 percent of progress. The distribution of the progress bar in this scenario can viewed in Figure 4.6. This violated to the uniformity requirement (cf. Requirement 3).

Figure 4.6: Progress distribution of lifecycle with 6 states

Making no backward step at the progress is defined in Requirement 4. This requirement refers exclusively to a static process. A backward step can only generated with a wrong prediction and a non-uniform progress.

> **Requirement 4.** *No backward progress*
> At a progress bar no backward progress is permissible. Progress means fundamental improvements through significant changes to existing conditions or processes.

For example, the lifecycle of Figure 4.5 with 2 paths can be seen. The first path includes 6 states and the second path 2 states. In the case, that the second path is taken for the progress determination the progress increase up to 50 percent (1 of 2 states) with the completion of the first state. However, if the first path with five (and not one) more states is taken the progress can be adapt in two ways. First, the remaining progress is shared with the remaining states. Or second, the progress is calculated again with six states and one completed states. Each states represented with the Requirement 3 *Uniform progress* about 16.67 (1 of 6 states) percent progress. With one completed state the progress is jump back after completing the first state from 50 percent to about 16.67 percent.

Further, all design choices must be clearly specified. The calculation of a progress value is surjective. For each constellation of states and steps in a lifecycle process instance one progress percentage is determined. For another constellation of the lifecycle another

percentage must be calculated. This is described the statement of following Requirement 5.

Requirement 5. *Unequivocally progress*
Progress must be defined uniquely, i.e no alternatives are permitted.

In the following Section the specified research questions are discussed. Therefore, several sub-research questions are introduced and discussed with various options. One of these options is chosen as a design choice to answer each research question itself.

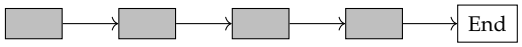
4.3 Research Analysis and Design of the PPD-Method

To determine the PPD-Method with Research question 1 and 2 several sub-research question are discussed. After the discussion of the research question with several options, one design choices describes the solution of this discussion. The summary of all design choices represents the PPD-Method.

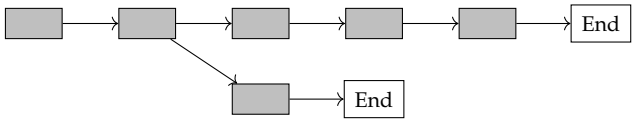
4.3.1 Determining state-based view lifecycle progress

Research question 1. How can progress of a lifecycle process in its state-based view form be determined?

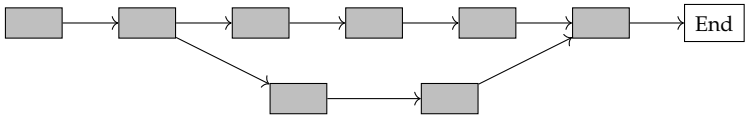
Context. State-based view can be regarded as a graph. Therefore, states σ of the state-based view identify the vertices V of a graph G and the transitions τ identified the edges of a graph (with $G = (V, E)$). All transitions in a state-based view are directed. Figure 4.7 gives four different examples of state-based views. In the first Example of Figure 4.7.a a linear state-based view is shown. This is the most trivial case. All states are connected sequentially with only one end state and with no decision states or join states. During run-time, only one state in a state-based view can be marked as *Activated*. Therefore, only one path of state-based view can be executed. In Figure 4.7.b-d several state-based view lifecycles with various decision and join states can be viewed. For each possible state-based view lifecycle a uniform metrics must be identified.



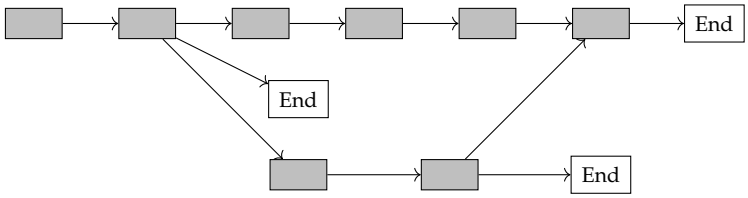
(a) Linear state-based view



(b) Non-linear state-based view with a decision state



(c) Non-linear state-based view with a decision and join state



(d) Non-linear state-based view with several decision and one join state

Figure 4.7: Four examples of lifecycle process structures

Problem statement. In general, Research question 1 cannot be answered directly. First, progress of linear state-based view is determined to define basics about progress calculation in a state-based view. Then these basics are verified for a non-linear state-based view. Afterwards, progress determination can be discussed for non-linear state-based view lifecycles. For this reason, two sub-research question must be answered. For the first sub-research question, more sub-research questions arise for linear lifecycles, which define the basics. This includes questions „What is 0 or 100 percent in a state-based view lifecycle?“, „How can progress be determined generally?“, and „What is the effect of progress in small lifecycles?“. Then the second sub-research question of complex lifecycles with branches and rejoins are discussed. Therefore, several possibilities and options for determining progress in a non-linear state-based view lifecycle are considered in further sub-research questions. After design choices are made for all sub-research these results can be combined (as in Figure 4.2a of the organisation V-Model). Research question 1 provide a solution for the PPD-Method

Sub-Research question 1.1. How can progress of a **linear lifecycle process** in its state-based view form be determined?

Context. First the basic decisions to calculate progress in a linear state-based view lifecycle is define. Therefore, Figure 4.8 shows an example of such a linear, static state-based view lifecycle. In this case, no decision states are included. This follows all states are executed one after the other. This is one of the trivial examples to calculate progress in percent. In this case, the second state is marked as an active state. This is shown with the colouring of the state in yellow and additionally, with the label Active.

Figure 4.8: State-based view lifecycle: 5 linear states and no decision states

Problem statement. Intuitively (only with a look at the diagram without any calculation or given reasons), a progress between 20 and 40 percent can be assigned to the state-based view lifecycle of Figure 4.8. With this intuitive assessment, the following defined metrics or design choices can be compared, but the front-end of PHILharmonicFlows needs metrics in any case. Without these, no appropriate calculations can be defined for online automatic progress determination. To determine the percentage of progress (not intuitively) of state-based view lifecycle several definitions and details are missing.

To calculated the progress of this state-based view lifecycle, 0 and 100 percent must be defined first. Second, the possible amount of progress for each state in a state-based view should be define. This are discussed in the following Sub-research questions.

Sub-Research question 1.1.1. How can 0 percent progress of a linear lifecycle process in its state-based view form be defined?

Context. The 0 percent mark of a lifecycle during run-time is needed for the calculation and presentation of the total progress. In addition, the 0 percent mark is needed as reference point and benchmark for the progress calculation of a lifecycle. During run-time, lifecycle process instances θ^I of a object instance ω^I are created. In the *Job Offer* process of the running example, a job offer is created. Therefore, a lifecycle process instances θ^I of the *Job Offer* object instance ω^I is instantiated. For all received *Applications* a new lifecycle process instances θ^I *Application* is instantiated. For all instantiated lifecycle process instance, the PPD-Method should be defined a 0 percent mark.

Problem statement. In this context, to defining 0 percent of a lifecycle process instances several possibilities exist. The defined 0 percent mark must be defined uniformly and generically. However, various 0 percent mark exists. For example, a point before the lifecycle process instance is created, at the moment of the creation, or a 0 percent mark after the creation of the lifecycle process instance are possible.

- **Option 1:** Before lifecycle process instance creation: The time before a lifecycle process instance is created. In this case, the progress increases to more than 0 percent after instantiation.
- **Option 2:** At the creation of a lifecycle process instance: During instantiation, 0 percent of progress are assigned. After instantiation process an instance exists and can be executed. In this case, the progress increases to more than 0 percent after instantiation, too.
- **Option 3:** After lifecycle process instance creation: The progress increased during the run-time of the lifecycle process instance but only after the creation.

Discussion. Option 1 defines 0 percent mark of a lifecycle process instance before the instances is created. Technically this cannot be implemented. An instance of a lifecycle cannot be assigned with progress value before its existence. For this reason, Option 1 is not a solution for the Sub-research question 1.1.1. Option 2 states that the lifecycle process instance should receive 0 percent progress at the time of instantiation. For example, a lifecycle process instance *Application* is created with the receipt of an application. At this very moment the new instantiated lifecycle process instance for this application is created. After instantiation process instance exists and can be executed. Therefore, progress of the lifecycle instance is generated more than 0 percent. This Option does not violate the requirements and is technically feasible. In Option 3 the progress calculation of a lifecycle process instance starts after the creation of this instance. For example, after the first state of the lifecycle is completed (state is marked as *Confirmed*) the progress arose

by 20 percent (with 5 states at the lifecycle). In this case, the progress is not defined at the point in time of the creation of the instance. For this reason, Option 3 is not a solution for the Sub-Research question 1.1.1. For this reason, Option 2 is defined the design choice for the Sub-Research question 1.1.1. The answer of the Sub-Research question is given in the following Design choice 1.

Design choice 1. 0 percent progress of a lifecycle process instance is assigned at the point in time of the creation of an instance (Option 2). The progress increases with the start of the execution of the first state in this lifecycle.

In the following sub-research question the 100 percent progress point of a lifecycle process instance is determined. This includes the question of when 100 percent progress may be displayed in a progress bar for an lifecycle process instance.

Sub-Research question 1.1.2. How can 100 percent progress of a linear lifecycle process in its state-based view form be defined?

Context. Each progress bar for each lifecycle process instance should reach the 100 percent progress. This statement is necessary because of Requirement 2 *Full progress bar utilisation*. For this reason, a point after the execution of the lifecycle process instance is not possible. Therefore, a point during the lifetime of the instance must defined as 100 percent progress.

Problem statement. To calculated the progress of a linear lifecycle the 0 and 100 percent mark of the lifecycle process instance should be defined. The 0 percent progress point was defined in the previous Sub-Research question 1.1.1.As for the 0 percent mark several options to define the 100 percent mark exists.

- **Option 1:** After completing the linear lifecycle process instance: The lifecycle process instance is assigned the 100 percent progress point after the lifecycle is completed. This means all states of the lifecycle process instance are marked as completed.
- **Option 2:** One end state of a linear lifecycle is marked as *Activated*: The 100 percent progress point is defined as the time the lifecycle process instance completed all previous states of their lifecycle except the end state. The end state is marked as *Activated*.

Discussion. In the first Option the progress is assigned 100 percent only when all states are marked as *Confirmed*. This is not compatible with the semantics of lifecycle execution,

in which an end state always remains achieve. Since the mark of 100 percent never occurs, it cannot be used as a design choice for the Sub-Research question 1.1.2.

The second Option describes the 100 percent mark of a lifecycle process instance with the marking of an end state as *Activated*. This is a possible option, because the 100 percent mark is inside of the lifecycle. Marking a state as *Activated* allows its execution. Normally, 100 percent can only be reached after a state has been executed. However, an end state of a lifecycle does not require any work effort (an end state is always a state with an empty step). For this reason, the end state required no work or effort when it is marked as *Activated*. The Design choice 2 of the Sub-Research question 1.1.2 defines the 100 percent mark of a lifecycle process instance with marking an end state as *Activated*.

Design choice 2. 100 percent progress of a linear lifecycle process instance is set with the marking of an end state as *Activated* (Option 2).

Often a small number of states exist in a lifecycle. A progress range can be assigned to each of these states. A linear lifecycle with ten states is assigned 10 percent progress per state. This leads to Requirement 3 *Uniform progress*.

Sub-Research question 1.1.3. How can a range of possible progress of a linear lifecycle process in its state-based view form be determined?

Context. In a lifecycle with just a few states, the progress calculation has a great potential range of progress for each state. Figure 4.8 shows an example of a lifecycle with five states. The progress bar of this lifecycle (with 5 identical sizes of states) can be seen in Figure 4.9.

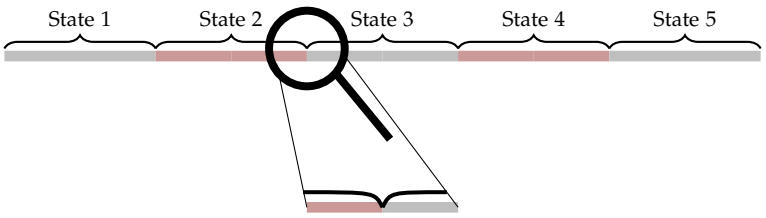


Figure 4.9: Progress distribution: Gray-red bar represents the progress bar

The calculation of the interval is trivial in a linear, non-dynamic progress with same weighted states. All states have the same range size of percentage in the progress bar. To calculated the progress of a linear lifecycle variables are defined. Table 4.1 shows all necessary variables to calculate and define the progress interval of each state in a lifecycle.

n	-	Number of states
size	-	Size of interval
min	-	Minimum of interval
max	-	Maximum of interval
i	-	i-th state

Table 4.1: Useful variables to calculate the progress interval of a lifecycle

The variable n describes the number of all existing states in a lifecycle. In state-based view of lifecycle of Figure 4.8 the variable n has the value 5, because five states exists in this lifecycle. The variable *size* can be calculated with the variable n as $size = \frac{100}{n}$. This variable describes the size of an interval of the progress bar. In this case, all states have the same weight. This results in all states also having the same interval size. The variable *min* and *max* gives the lower and upper boundary of the progress of one specific interval. The last variable i represents the i-th state of the linear process. In the lifecycle of Figure 4.8, the active state is the second state, therefore $i = 2$.

Problem statement. The next two mathematical formulas are used to calculate the minimum and the maximum of the i-th state in a process. The problem is that these two formulas are not unambiguous, because the boundaries between two states overlap.

$$min(i) = (i-1) * size \quad \& \quad max(i) = i * size$$

In state-based view lifecycle of Figure 4.8, the maximum of the first state has the same percentage as the minimum of the second state. The percentage of the process must be well define. To archive this, the following options are possible.

- **Option 1** Progress interval of a state in a lifecycle in percent: $[min, max]$. Both boundaries are included in the interval of a state.
- **Option 2** Progress interval of a state in a lifecycle in percent: (min, max). Non of the two boundaries are included in the interval of a state.
- **Option 3** Progress interval of a state in a lifecycle in percent: $[min, max)$. The minimum is included in the interval of a state but the maximum is not. This interval is defined with the minimum and the supremum of the range.
- **Option 4** Progress interval of a state in a lifecycle in percent: $(min, max]$. The maximum is included in the interval of a state but the minimum is not. This interval is defined with the infimum and the maximum of the range.

Discussion. Option 1 is shown in Figure 4.9. All boundaries between the states overlap. This Option violates the Requirement 5 *Unequivocally progress*. For this reason, Option 1 can not be the solution to this Research question.

Option 2 is the opposite of Option 1. In this Option, no boundary can be represented in the progress bar. In the lifecycle of Figure 4.8, the percentage values of 0, 20, 40, 60, and 80 are never displayed on the progress bar. Furthermore, not all percent values are shown there. This Option violates Requirement 2 *Full progress bar utilisation*: The progress bar must be fully used, most importantly the 0 and 100 percent progress values.

Option 3 includes the minimum of a progress interval for a state but not the maximum. Only the supremum exists. In the lifecycle of Figure 4.8 the second state represent a percentage of $[20, 40)$. This describes an interval from 20 up to 40 percent excluding 40 percent (all values greater or equal than 20 and less than 40). After execution of all states the last state can not obtain 100 percent of progress. This Option requires a special case for 100 percent progress, because of Requirement 2 *Full progress bar utilisation*. Without a special case for 100 percent this Option cannot be chosen as the solution to the Sub-Research question 1.1.3. This is already defined with Design choice 2.

Option 4 is the opposite of Option 3. The minimum is not included in the interval. Only the infimum. The maximum, however, is part of the interval. In the state-based view lifecycle of Figure 4.8 the first state represented a progress between $(0, 20]$ percent. In this Option, 0 percent of progress need a special case, because of Requirement 2 *Full progress bar utilisation*. Without a special case for 0 percent this Option can not be the answer of the Sub-Research question 1.1.3.

After the consideration of Option 1-4 Option 1 and 2 are not a viable solution for Sub-Research question 1.1.3. To find a solution and a design choice for this Sub-Research question 1.1.3, Option 3 with a special case for 100 percent or Option 4 with a special case for 0 percent are possible. For this reason, it must be examined which Options fits better to the object lifecycle progresses.

The structure of a lifecycle organises states sequentially. It is not important for this consideration, whether the lifecycle is linear or with branches. In Figure 4.7, four patterns of lifecycle process structure are given. In a lifecycle with decision steps and several end states only one end state may be reached. No parallel execution is possible.

All states of the lifecycle may involve steps. However, the end states include only one empty step. The fact of the empty end state and Design choice 2 Option 3 suits better than Option 4, because the end state displays 100 percent and the others steps displays 0 to 99.99 percent of the progress. In a lifecycle process all non-end states have the same size and weight, only the end states are significant smaller. In a linear lifecycle with one

end state the used variable n (number of states) for the calculation of s (size of a interval) must be modified as $s = \frac{100}{n-1}$.

Design choice 3. $[min, max)$ (Option 3) represent the progress interval. The end state represents 100 percent.

Example 1. Figure 4.10 shows a process example with an active state and an end state. In this example, 5 states are given. The end state represents 100 percent. Therefore, four non-end states are given. This results in the first state representing $[0, 25)$ percent, the second (active) state representing $[25, 50)$ percent, the third state representing $[50, 75)$ percent, the fourth state representing $[75, 100)$ percent and the end state (fifth state) represents 100 percent.

Figure 4.10: Linear lifecycle process with an active and an end state

Design choice 3 is defined in Metric 1. With this metric a progress of a lifecycle process can be split into several intervals. With this metric and design choice Sub-Research question 1.1 cannot be answered yet. Only a range of progress can be given.

Metric 1. The progress interval of all states excluding the end state is represented as:

$$[min, max) \text{ percent}$$

with $min(i) = (i-1) * s$, $max(i) = i * s$ and $s = \frac{100}{n-1}$ (-1 because of the exclusion of the end state) using the variables defined in Table 4.1. The end state is represented as:

$$100 \text{ percent}$$

Metric 1 defines the progress interval of a process and defines the 100 percent mark. The interpretation that 100 percent represents the end state also works with more than one end state, because only one end state per lifecycle process instance is reached. For answering the initial Research question 1.1 a defined percentage value of the progress interval of a state must be chosen.

Sub-Research question 1.1.4. How can progress intervals be broken down to a percentage?

Context. At the moment, states are mapped to progress intervals. For display on a progress bar a single value is needed, e.g. 75 percent.

Problem statement. The argumentation with several progress intervals, which overlap is significantly more complex, chaotic and difficult to understand than with a single percentage. One percentage is much more simplistic and can be displayed on a progress bar. In Chapter 2.3, progress methods from project management are presented. All of these methods are possible solutions for Sub-Research question 1.1.4

- **Option 1:** The 0-100-Method from Definition 10: A state is measured with 0 percent progress as long as it has not left the *Activated* marking.
- **Option 2:** The 20-80-Method from Definition 11: This method has its basic idea from the 0-100-Method. This method is different because at the beginning (as soon as a state receives the marking *Activated*) 20 percent progress of the state interval is given. With completing the active state (and change the marking to *Confirmed*) the missing 80 percent of the state is added.
- **Option 3:** The 50-50-Method from Definition 12: This method is also based on the idea of the 0-100-Method. At the beginning (as soon as a state receives the marking *Activated*) 50 percent progress of the state is given. With completing the active state (and change the marking to *Confirmed*) the missing 50 percent of the state are added.

Discussion. Option 1, the 0-100-Method is the most conservative method for measuring progress in a state interval of the state-based view lifecycle. For the active state in the process example from Figure 4.10 the progress is at 25 percent from the change into the *active* state and during the whole time of being marked as *Activated*. With the change into the marking *Confirmed* at the end of the execution of the second state (and marking the next state as *Activated*) the progress increases to 50 percent. States, which can be executed very fast this method is a good choice. An example is a state which automatically creates a form for registration on an online-platform where users are only fill in their name, e-mail, and password. On the other hand, states, which take a lot of time and the main work is not to fill the results in the form, but rather the information procurement, the 0-100-Method is not the best choice. If the information procurement requires several days a progress is always remaining the same value might be frustrating for a user.

Option 2 and 3 gives progress (20 and 50 percent of a state) with the start of the execution of this state. Some percent of progress are given as motivation (or other reasons) at the beginning and the missing percentages to completed the 100 percent are given at the time the state is finished. In the example from Figure 4.10, the active state is at 30 percent (20-80-Method) or 37,5 percent (50-50-Method) after the change into the marking *Activated*, respectively. At the end of the state execution the missing 20 percent or 50

percent of the progress bar (80 percent or 50 percent of the state) are added. Thereby, the progress given at the start is larger than the actually progress. Less progress is needed for the completion of the state. For a user this might be a better experience than Option 1.

None of these options is optimal for this problem. In large state-based view lifecycles the difference of the options pass unnoticed anyway. But for small lifecycles the selection of the option becomes more important. To answer this Sub-Research question 1.1.4, Option 1 is used for now. On the one hand, this Option shows the minimal progress in a process at all time. On the other hand, Option 2 and 3 shows only 0 percent progress during design-time. At run-time the progress of the first state starts with 20 or 50 percent of the range of the first state. Additional Option 2 and 3 violates Requirement 2 *Full progress bar utilisation*. The Design choice 4 is only for this first consideration of calculating a single percentage of a progress interval for a state.

Design choice 4. The 0-100-Method determining the single percentage of a progress interval of a state is used.

The Design choices 1 to 4 are summarise to a higher-level Design choices as the V-Model describes.

Design choice 5. 0 percent progress of a lifecycle process instance is determined at the creation of this instance (Design choice 1). The progress increases with marking the following state as *Activated* (Design choice 4). The 100 percent progress is determined with marking an end state of the state-based view lifecycle as *Activated* (Design choice 2). The boundary of a progress interval for each state is calculated with the minimum and the supremum as $[min, max)$ with $min(i) = (i-1) * s$ and $max(i) = i * s$ with $s = \frac{100}{n-1}$ and i as the i-th state of the linear state-based view (Metric 1 and Design choice 3).

Further, the design choices are considered for a non-linear lifecycle and are adjusted as necessary. Therefore, lifecycles are again considered as a states-based view. Non-linear lifecycles are generally more common than linear lifecycles.

Sub-Research question 1.2. How can progress of a non-linear lifecycle process in its state-based view form be determined?

Context. So far, all discussed Sub-Research question considered linear lifecycles only. However, linear lifecycles are rather a special case and non-linear lifecycles are more common. Non-linear lifecycles are created with decision states (path of states can be spilt) and join states (merge path). Therefore, paths with different length of states must be considered. In paths of different lengths, a prediction about the expected number of states

to be executed is needed to calculate the interval for each state. An Example of a non-linear lifecycle is shown is Figure 4.11. Additionally, several example of various lifecycle structures were introduced in Figure 4.7. For all these possible lifecycle structures, a metric and design choices must be defined to determine progress. The properties of lifecycles significantly limit the possibilities of options for a metric or design choice to calculate the progress of each lifecycle. These are: only one start state and at least one end state exist, all states are connected with directed transitions, no loops are possible, and no parallel execution of two or more states of one lifecycle process instance is allowed.

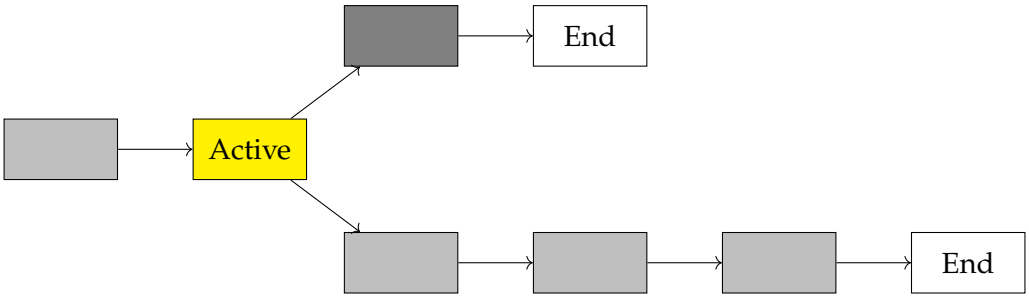


Figure 4.11: Example of state-based view lifecycle with a decision state

These are not all properties of a lifecycle but the relevant ones to minimise the options of progress determination. With the fact of only one start state, no loops and no parallelism in a lifecycle, all non-linear lifecycles can be viewed as a linear lifecycle in which the linear path is not known at the start of the lifecycle. 0 percent progress in a non-linear lifecycle is defined the same way as in a linear lifecycle, because only one start state exists. Further, a start state can be a decision state. However, this only effects the progress of the following states and not the start state itself. In a non-linear lifecycle, mostly more than one end state exists. However, only one of them is reached and executed. The other end states are marked as *Skipped*. For this reason, the Design choice 2 can also be transferred to a non-linear lifecycle. The boundary of a progress interval can also be defined with the minimum and the supremum. However, the size s to calculated this boundaries should be adapted. In a non-linear lifecycle the size is calculated with the formula $\frac{100}{n-1}$. The variable n describes the total number of states in a lifecycle. In a non-linear lifecycle some states are skipped. For this reason, the variable n should be adapted to the number of states that is actually executed.

Problem statement. Most lifecycles in a object-aware business process are non-linear. Often more than one decision state is present in a lifecycle. This creates several paths. It is possible that paths join again into one path (several examples of a structure are shown in Figure 4.7). To understand the problem statement of this Sub-Research question, Figure 4.11 is considered. The existing method (Design choice 5) to determined the progress of a lifecycle is not applicable in this case. There are a total of 6 states (without the end states)

and one state is already completed (marked as *Confirmed*). This results in 16.67 percent progress for the lifecycle process Example of Figure 4.11. Because of the decision state not all states are executed. For example, if the active state chooses the upper path three of the six states are never executed. When the end state of the upper path is marked as *Activated* the lifecycle is finished and is represented 100 percent progress. However, with the method of Design choice 5 the progress bar of the lifecycle shows at most almost 50 percent progress (because of the right open interval) with the end of the state from the upper state (marked with dark grey). In the following state, the end state of this path, 100 percent is assigned. In this case, the progress jumps from 50 percent up to 100 with reaching the end state. This violets against the Requirement 5 *Unequivocally process*. For this reason, new options must be discussed resulting in a new design choice, which is determined the progress of a non-linear lifecycle correctly. The possible options are shown in the following lists.

- **Option 1:** Shortest path in the lifecycle: This method calculates the shortest path from the active state to an end state without the end state (see Decision choice 3). The total number of states are the result of the shortest path added with the completed states and plus 1 to take the active state into account. This results in:

  predicted total path length = shortest path + completed states + 1

  Therefore, the progress is calculated with the completed states in relation to the determined total states of the shortest path.

- **Option 2:** Longest path in the process: The length of all paths from the active state to all possible end states (excluding the end state) should be determined. The total number of states are the result of the longest path together with the completed states and plus 1 (active state). This results in:

  predicted total path length = longest path + completed states + 1)

  Therefore, the progress is calculated with the completed states in relation to the determined total states of the longest path.

- **Option 3:** Average of all path length in the process: In this Option, the length of all possible paths from the active state to any end states (excluding the end state) are calculated. In a second step the average of all path lengths are calculated. The total progress results from the amount of completed states, the average of all possible path lengths to an end state and plus 1 (active state). This results:

  predicted total path length = average of paths + completed states + 1

  Therefore, the progress is calculated with the completed states in relation to the determined average amount of states of all possible paths.

Discussion. To find the advantages and disadvantages of Option 1 the state-based view lifecycle of Figure 4.11 is contemplated. In this case, the progress of the lifecycle is calculated again after changing the active state (the active state change there marking into *Confirmed* and the following state is marked as *Activated*). The progress of the Example of Figure 4.11 is calculated with Option 1 as follows: The shortest path from the active state to an end state is 1 (excluding the end state). The end state is excluded because of the distribution of the interval of progress, see Design choice 3. The total number of states is 3 (number of completed state plus 1 for the active state plus number of shortest path). The current progress of the lifecycle for the active state in Figure 4.11 is 33.33 percent (1 of 3, with the 0-100-Method of Design choice 4). The currently active state decides, which path is taken. For the first path the lifecycle may choose is the upper path. In this case, the first state of the upper path is marked as *Activated*. Due to the change into a new active state the progress is recalculated. In this case, only one path exists. This results in the shortest (and only) path is 0, because the following state is an end state. The total number of states is 3 (2 completed plus 1 active plus 0 of shortest path). This results 66.66 percent of progress. The next possible state is the end state. With marking the end state as *Activated* the progress reaches 100 percent. In this case, the progress shows a constant and regular progress. For the second possible path the lifecycle may be chosen is the lower path. Again, the active state of lifecycle Example of Figure 4.11 determined 33.33 percent. In this case, the lifecycle is chosen the lower path and the first state of the lower path is marked as *Activated*. The progress is calculated again. Thereby, the shortest path (there is only one path - the lower one) results 2 (again excluding the end state). The number of completed states is 2. This results in a total number of states of 5. The progress produced a progress of 40 percent (2 of 5 states).

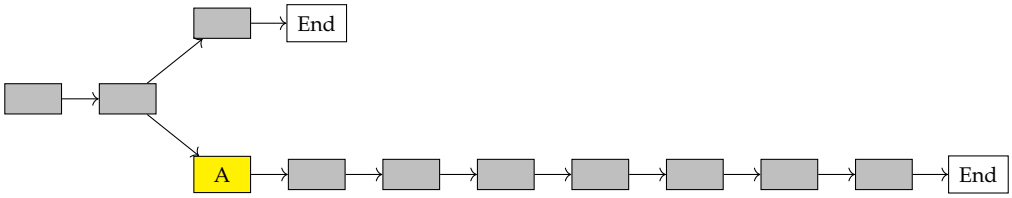


Figure 4.12: Example with five more states in the lower path of state-based view lifecycle

An Example of a state-based view lifecycle with a much longer lower path is shown in Figure 4.12. Using Option 1 and assuming the lower much longer path is activated, the progress calculated after this decision is result in a backwards jump of the progress. For illustration the progress of this larger lifecycle with 5 more states than the one in Figure 4.11 is calculated at 20 percent progress (2 of 10 states) for the active state. In this case, the progress made a backward step from 33.33 percent down to 20 percent with the change from the decision state to the active state of Figure 4.12. The progress development of this example can be viewed in Figure 4.13. In all cases, with large differences between

two or more paths a backward step of progress after a decision state is possible. However, progress is often described as fundamental improvements through significant changes in existing conditions or processes. This describes the Requirement 4 *No backward progress*. For this reason and the possibility of negative progress Option 1 is not chosen as the solution for Sub-Research question 1.2.

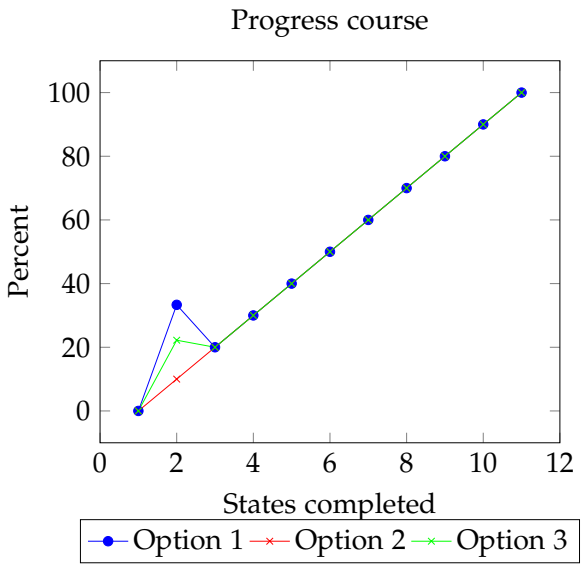


Figure 4.13: Progress curve of the lifecycle of Figure 4.12 by taking the lower path for each of the three options. The 11th state represents the end state and the 100 percent mark.

Option 2 is based on the longest path. The lifecycle Example of Figure 4.11 results in a progress for the active state of 20 percent (1 of 5 states, one completed state plus one active state plus the number of states on the longest path, in this case 3). The active state is a decision state. In the first case, the active state decides for the upper path and the following state is marked as *Activated* and the progress is calculated again. The upper state is chosen and the longest path is calculated with 0. This represents progress of 66,66 percent. In this case, a jump from 20 percent up to 66.66 percent can be observed. In all cases that a lifecycle takes a shorter path than the longest path the progress makes a big jump. For the lower path the progress grows by 20 percent after for each completed state periodically and constantly up to 100 percent by the time the end state is marked as *Activated*. Compared to Option 1 this Option does not allow the progress to jump back, but larger forward jumps are possible.

The last Option 3 aims to find a compromise between the first two options. This means, all path to an end state are calculated. In this case, there are two possible paths. These

paths are 1 and 3 states long. The average of this paths length is 2. This results in a progress of 25 percent (1 of 4 states, 1 completed plus 1 active plus 2 averages states per possible path). When the active decision state activates the upper path the new progress is 66.66 percent(2 of 3 states, no other paths are possible). In the other case, the lower path is activated the progress goes to 40 percent (2 of 5 states).

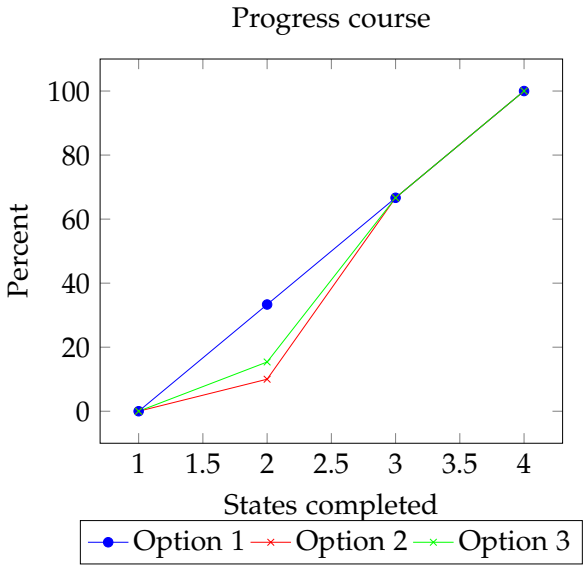


Figure 4.14: Progress curve of the lifecycle of Figure 4.12 by taking the upper path for each of the three options. The 4th state represents the end state and the 100 percent mark

Figure 4.14 shows a diagram about the progress performance of the lifecycle from Figure 4.12. In this diagram, the active state of the lifecycle chooses the upper path. This path is shorter than the lower one. Each of the three curves represents one of the given options. In this case, Option 1 is the optimal option, because this Option has correctly predicted the path. However, the others two options are more interesting for this discussion, because the progress curve predicted the wrong path. Both options predicts a longer path. This results in less progress than in the correctly predicted option. This is not optimal, but also no big disadvantage. After the decision state the progress is calculated again and the curve is adapted. In this case, the progress increased faster than in the correctly predicted option for compensation purposes.

The progress course in Figure 4.13 shows the execution of the lower path (of the lifecycle in Figure 4.12) for comparison of all three option. In this diagram, Option 1 and 3 violates against the Requirement 4 *No backward step*. For a purely graphical view, only Option 2 can be selected for the Design choice 6.

Design choice 6. The longest path (Option 2) is calculated for the prediction of a non-linear lifecycles.

In the last part of the state-based view discussion the following Sub-Research question 1.3 is analysed. In all previous research question same weighted states were assumed.

Sub-Research question 1.3. How can progress of a lifecycle process with differently weights of state in its state-based view form be determined?

Context. In all previous Sub-Research question the states are considered to have the same weight. However, it can happen that one state of a lifecycle requires more work and therefore, this state should be given a higher weighting. In Figure A.1 of the appendix the lifecycle *Job Offer* is given. This lifecycle contains five states. Two of them are end states: *Position Filled* and *Position Vacant*. In this lifecycle, a decision step is given in the third state. This is the reason for the two end states. How a decision state in a lifecycle is handled was clarified in the Sub-Research question 1.2. For the following problem statement the second end state and the branching can be ignored. In this case, only three states and one end states exist. Furthermore, in general the execution of different states in a lifecycle never takes the same time. The time and effort required to process a state varies from state to state, resulting in different duration.

Problem statement. In the *Job Offer* lifecycle of Figure A.1 this problem can be viewed. The first state *Preparation* of the lifecycles includes: *Title*, *Description*, *Category*, *Tasks* and *Qualifications*. This state requires considerably more effort (work and time) than the second state, for example. In the second state *Published* the job offer is published. In this case, only a date is set. Often this is the date of today. In the first state significantly more information has to be collected and provided. Additionally, filling in the form again needs more time and work than for the second state. For this reason, a solution is needed for allowing the calculation of progress of a lifecycle with different weight of non-end states. In this sub-research, question an individual state with its steps should not be viewed. This is part of the following major Research question 2. In this Research question, options for different possible weights are discussed. This includes how numeric weighs can be define. Therefore, a metric to handle assigned weights of non-end state should be define. Or the calculation of the variable s from Metric 1 should be adapted or extended for weighted states. Therefore, the following options exist.

- **Option 1:** All numbers can be used as weights for non end states ($w \in \mathbb{R}$, w as weight).
- **Option 2:** All non-negative numbers can be used as weights for non-end states ($w \in \mathbb{R}_0^+$, w as weight).

- **Option 3:** All positive numbers can be used as weights for non-end states ($w \in \mathbb{R}^+$, w as weight).
- **Option 4:** All natural numbers can be used as weights for non-end states ($w \in \mathbb{N}$, w as weight).

Discussion. The first Option chooses all possible rational numbers including negative numbers. With this options, all for non-end states of a lifecycle can be calculated with negative weights. Therefore, negative progress of a lifecycle can be generated. Because of this effect, Option 1 is not a possible option for using weights for non-end states. Option 2 considered all non-negative numbers as a weight for non-end states. In this case, any non-end states can be assigned a zero-weight. However, if all non-end states of a lifecycle are given with a zero-weight no progress exists at all. Therefore, no progress determination is possible. Therefore, the second Option is also not a possible option for using weights for non-end states, because of this definition gap with zero-weights. In Option 3 a zero-weight is not possible. This Option can be implemented with no definition gap. However, the positive real numbers can become very confusing as there is an extremely high number of possibilities (uncountable infinite) and should therefore be restricted. The last Option allows only natural numbers. This includes all integers greater than zero. As for any option an upper boundary is needed. Given a non-end state with a weight of 999 in combination with other non-end states with a weight of 1, it is difficult to measure meaningful progress. In this extreme example, the non-end state with a weight of 1 equals not even 0.1 percent and the second state equals the remaining 99.9 percent. These unhelpful and unrealistic relations between several non-end states should be avoided. For this reason, weights of $w \in \{1,5\} \in \mathbb{N}$ offers a meaningful but not too limited weight distribution. It is not important whether the upper boundary is 5 or 6 great. However, 5 different weights can be split well in the following conditions: 1 - rapid, 2 - fast, 3 - normal, 4 - slow and 5 - sluggish. Further, a default value can be defined. The intuitive choice is 3, the midpoint of the scale. With the default value the following metric works with weighted and unweighted states. In the second case the non-end states are assigned with weights, however, with the same for each. This has no effect in comparison with non weighted states. Furthermore, an end state also needs a weight, however, this states does not require any effort. For this, all end states are automatically weighted with $w = 0$. There is no option to assign other states a weight of zero.

Design choice 7. Possible weights for non-end states are: $w \in \{1,5\} \in \mathbb{N}$. The interpretation of these weights of a state are: 1 - rapid, 2 - fast, 3 - normal, 4 - slow and 5 - sluggish. The default is set with the value 3. All end states are automatically assigned $w = 0$.

For the calculation of the progress interval Table 4.1 must be extended. The additions are shown in the following Table 4.2.

w_i	-	Weight of the i-th state
w_A	-	Weight of the active state
w_{total}	-	Sum of all the execution path
W_{comp}	-	Weight of all completed states (marked as *Confirmed*)
S_{pred}	-	All states of the predicted execution path
W_{pred}	-	Weights of the predicted execution states

Table 4.2: Addition to Table 4.1: Variables for calculation with weights.

In combination with weights Metric 1 can no longer be used and must be adapted. For this reason, Metric 2 is defined describing the calculation of a progress interval with weighted and unweighted states via an default value.

Metric 2. The progress interval of all states excluding the end state is represented as

$$[min, max) \text{ percent}$$

with $min(\sigma_i) = \frac{w_{completed}}{w_{total}}$, $max(i) = \frac{w_{completed}+w_A}{w_{total}}$ and variables defined in Table 4.1. Any non weighted state is assigned the default weight 3.

For a linear lifecycle process instance the sum of all weights is $w_{total} = \sum_1^n w_i$ and the size of the interval is $size = 100 * \frac{w_A}{w_{total}}$ with variables defined in Table 4.2.

For a non-linear lifecycles the longest path is calculated with the weighted states ($w_i \in S_{pred}$), the weight of the active state, and all weights of completed states. This results in:

$$w_{total} = \sum_{i=1}^{|W_{pred}|} w_i \in W_{pred} + \sum_{i=1}^{|W_{comp}|} w_i \in W_{comp} + w_A$$

Only the weights of the longest path are added up for prediction. A reached end state represents

$$100 \text{ percent}$$

Metric 2 defines the determination of a progress interval with weighted and unweighted states (via a default value). For this reason, Metric 1 is no longer necessary and is replaced with the extended Metric 2. All sub-research question of the initial Research question 1 (*How can progress of a linear lifecycle process in its state-based view form be determined?*) were discussed. The following Design choice 8 summarises the previous design choices as the solution for the major Research question 1.

Design choice 8. The progress of a lifecycle process in its state-based view can be determined with Metric 2. Therefore, 0 percent is defined with the instantiation of a lifecycle process instance (Design choice 1). Further, the 100 percent is achieved with

marking an end state as *Activated* (Design choice 2). The boundaries of a progress interval for a state are defined with the minimum and the supremum (Design choice 3). For the calculation the interval Metric 1 is extended with the consideration of weights. This are defined in Metric 2. Possible weights for a non-end state are $w \in \{1,5\}$ with 1 - rapid, 2 - fast, 3 - normal, 4 - slow and 5 - sluggish (Design choice 7). The end state is assigned with a weight of zero. A single percentage from the progress interval can be determined with the 0-100-Method (Design choice 4). In non-linear lifecycles the longest path is calculated as a prediction (Design choice 6). The longest path of the lifecycle also corresponds to linear lifecycle. After calculating this path no additionally consideration is needed to determine progress in a non-linear lifecycle.

Further, the progress determination within a single state is defined. For the PPD-Method the determination of a single state is required for the active state. Therefore, the determined progress interval of a state from Design choice 3 is further improved. A single percentage is calculated with the consideration of a state internals. For this purpose, Design-choice 4 is replaced and big jumps of the 0-100- Method should be improved.

4.3.2 Determining Intra-State Progress

The determination of progress from a given progress interval by a pure observation of the state (this corresponds to a pure graphical observation) does not offer great accuracy. In lifecycles with few states the ranges of the passed states are large. In a lifecycle with only five states, where one of them is an end state, in an equal distribution (unweighted states) the progress interval is 25 percent of the total process. Since the 0-100-method creates big jumps in progress, a procedure is developed in this Section, which determines progress within a state. This is allow for more accurate representation of progress.

Research question 2. How can progress within a state of a lifecycle be measured?

Context. The answer of this Research question has strong effects on the progress. Especially when there are only few states in a lifecycle and each of this states maps a large progress interval. In the lifecycle Example of Figure 4.10 all states excluding the end state have a progress interval range of 25 percent (the first state $[0,25)$, the second state $[25,50)$, etc).

On the one hand, for a process involving many states, this Research question does not have such a major impact. For example, a process with 21 states (the 21th state is the end

state) each state has a progress interval range of 5 percent. The 12th state of this process, for example, has a progress interval between 55-60 percent. This range is so small that the Research question 2 has less impact. On the other hand, a progress involving only 3 states (the 3rd state is the end state) each state has a progress interval range of 50 percent. For this example, the first state has a progress interval between 0-50 percent. The minimum of the state shows no work was done and the maximum represents that half the workflow of a process was done. Often small numbers of states are used.

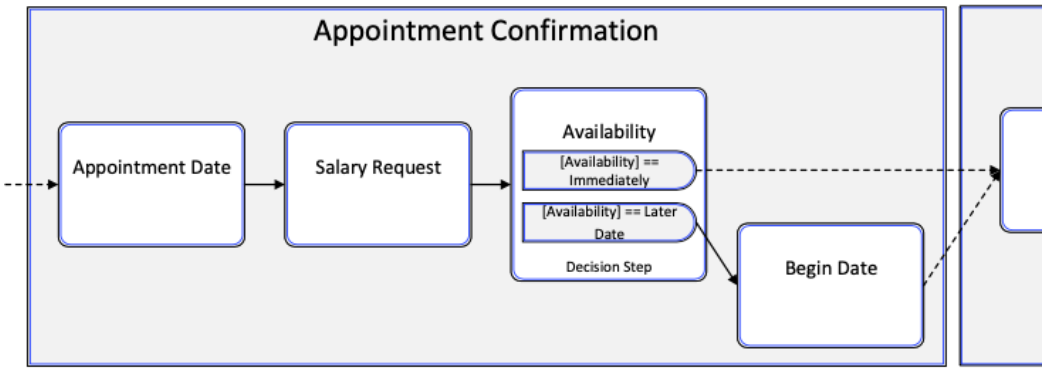


Figure 4.15: Part of a lifecycle *Interview*: A state with all corresponding steps and the transition to the following state.

Problem statement. The structure of a state looks like the structure of a lifecycle. In a state only one start step and any number of linear and non-linear steps are possible. Non-linear states can be created with decision steps resulting in multiple possible paths. Multiple paths in a state can join in one step after a decision step (between the decision step and the join step several steps can be present). Furthermore, all steps are connected in a non-circular path. However, one difference between the structure of a lifecycle and a state exists. Within a state no end step exists whereas one or more end state exist in a lifecycle. The end of a state is shown with the transition to the next state. In the case of Figure 4.15 two outgoing transition are given. Both of them activated the same following state. It is possible that any outgoing transition activates another state. To determine the progress of a step in a graph view (step-based view) the same approach as for the state-based view is evaluated. In the following the graph view of a state is referred to as step-based view. In literature this term is not define, however, for a better understanding of the discussion this term is introduced. The defined design choices of the state-based view are evaluated, whether they can also be used in a step-based view.

Sub-Research question 2.1. Which design choices of the state-based view of a lifecycle can be used for a step-based view and which require an adaptation?

Context. Generally, the structure of a state-based view of a lifecycle looks like the structure of the step-based view. Both views are directed graphs with possible decision and join points (state or step) and one start point (state or step). In Figure 4.15 the structure of a state with its steps can be view as an example. Based on the analogies, all chosen design choices for the Research question 1 are considered as an option to determine progress of a single state. Wherever this option is not possible or needs to be adapted, this is also addressed in the discussion.

Problem statement. The state-based view differs from the step-based view mainly in the fact that no end step within a state exists and the markings of a step are not the same as the marking of a state. The markings of steps are much more complex as described in Section 2.2.2.

Table A.2 and A.3 from the appendix describes the step data markings and data markings. Otherwise, the two views (state- and step-based view) are very similar. Therefore, the presented interval from the determined progress of a state in a lifecycle is considered as a interval from 0 percent up to 100 percent. Figure 4.16 shows an example with five states. The fifth is the end state and represents 100 percent (Design choice 2). The progress of the second state is examined more closely. Thereby, the calculated progress interval of this state is presented and considered as an interval from 0 to 100 percent when determining the progress within the state, as shown in Figure 4.16. All design choices from Research question 1 are considered as options for Research question 2. Thereby, any combination of options can be adopted for the design choice of this Research question.

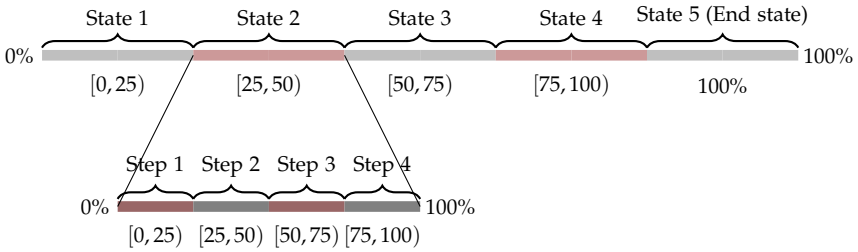


Figure 4.16: Progress distribution of a step from a passed state

- **Option 1:** 0 percent progress of a state is determine at the creation of this lifecycle process instance (Design choice 1).

- **Option 2:** 100 percent progress of a state is determined with marking the *end step* as *Unconfirmed* (Design choice 2).
- **Option 3:** $[min, max)$ represent the progress interval. The *end step* represents 100 percent (Design choice 3).
- **Option 4:** The 0-100-Method determined a single percentage of a progress interval of a state (Design choice 4).
- **Option 5:** The longest possible path is calculated the prediction of a non-linear state (Design choice 6).

Discussion. Option 1 defines the 0 percent of a progress interval of a lifecycle with the creation of the lifecycle process instance. The 0 percent mark of a state can also be defined with the creation of the lifecycle process instance. At creation of the lifecycle process instance all states are described with 0 percent. The 100 percent mark of a state is determined with the change of the state marking from *Activated* to *Confirmed*. This definition of the 100 percent mark is used and Option 2 is discarded. The main problem of Option 2 is it does not include an end state (which is never marked *Confirmed*) which is mandatory for a lifecycle. Therefore, Option 2 can not be implemented. In Option 3 the progress intervals of a step is defined the same way as the progress intervals of a state. With the same arguments of the Sub-Research question 1.1.3 the progress interval of a step is defined as $[min, max)$. The minimum and maximum can be calculated with Metric 1. Therefore, the variables of the metric are adapted as shown in Table 4.3. The variable n_{total} is defined as the predicted amount of execution steps in a non-linear state.

n_{total}	-	Number of predicted execution steps in a state
i_{step}	-	i-th step

Table 4.3: Additional variables to calculate the progress interval of a step in a state

However, an *end step* like the end state does not exist. In Figure 4.16, 100 percent is not included at the last step of the state. Additionally, the end state of a lifecycle needs no more progress calculation at the step-based view. Because with marking the end state as *Activated* the progress is determined 100 percent. Option 4 offers the 0-100-Method to determine the progress inside a step. In this consideration, a step is considered as an atomic unit. For this reason, the 0-100-Method is defined the determination of a single percentage of a step progress interval. Option 5 gives a variant to predict the path of a non-linear state with the longest path. Again with the same arguments as for Sub-Research question 1.2. All this are summarised the following Design choice 9.

Design choice 9. 0 percent progress of a state is defined with the creation of a lifecycle process instance. The 100 percent of state is defined with the change of marking from

Activated to *Confirmed*. The interval for a step is the same as for a state ($[min, max)$). Further, a step is considered as an atomic unit and the progress of this step is determined with the 0-100-Method. In a non-linear state the predicted execution path is calculated with the longest possible path method.

In the Research question 1 weighted states are discussed (Sub-Research question 1.3). Thereby, weights of $w \in \{1, 5\} \in \mathbb{N}$ were defined. Further, options to determine weights are considered in the following Sub-Research question 2.2.

Sub-Research question 2.2. How can different weights of a state with consideration of the step-based view be determined?

Context. In Sub-Research question 1.3 a design choice about the used method to calculated the progress in a lifecycle with differently weighted states is given. In this case, the states needs a variable for the state. This variable is $w \in \{1, 5\} \in \mathbb{N}$. The w stands for weight. The interpretation of this weights of a state are: 1 - rapid, 2 - fast, 3 - normal, 4 - slow and 5 - sluggish. Often different states of a lifecycles takes a different amount of time. In Sub-Research question 1.3 several reasons for different weighted states are given. In this sub-research question, some methods to generate these weighted states are investigated.

Problem statement. Only methods using the definition of the weight can be used as options for the following discussion. Others definitions, for example, a state needs 80 percent less progress or 30 percent more are also possible solutions but do not integrate with the design choice of Sub-Research question 1.3. For this reason, only options are considered where the weights have the scope of the variable w.

- **Option 1:** Manual allocation of weights: During modelling the lifecycles of PHILHARMONICFLOWS process weights can be allocated to each state manually. Weights can be readjusted before each re-run of the process.
- **Option 2:** Calculated allocation of weights: The number of the steps in a state yield in the weights of the state itself. For example, a single stage state results in a fast weight ($w = 1$).

Discussion. The first Option can be realised. All possible values for the weights and their interpretation (1 - rapid, 2 - fast, 3 - normal, 4 - slow and 5 - sluggish) are defined. The administrator of the PHILHARMONICFLOWS process can make adjustments to the weights set during or after run-time to improve the impact in the next process. These improvements must be done manually. This means an administrator (or other users) must recognise and adapt the inaccurate weight. For the second Option, the numbers of

steps are calculated from the predicted execution path of steps. This result can be used as the weight for the state. For more than five states in a step the calculation is determined a sluggish weight ($w = 5$).

Manual allocation of weights are used as the design choice. This variant is extended with the second Option. The modeller team of the business process can set the weights for each state manually. During the planing phase for a business process the weights can be discussed for each state. However, if there is no time for this discussion is available the PPD-Method determines the weights automatically. After few runs of the business process the weights can be readjusted with more accuracy. The combination of both Options define the following Design choice 10.

Design choice 10. Both Option are implemented. The manual allocation of weights are additionally extended with the automatically calculation of weights based on the numbers of steps.

In summary, the design choices of the Research question 1 and 2 with all their Sub-Research question define the PPD-Method. This is described in the general and last Design choice 11.

Design choice 11. The PPD-Method of a lifecycle process instance is assigned 0 percent at the point in time of the creation of an instance (Design choice 1). Further, the 100 percent mark is set with the marking of an end state as *Activated* (Design choice 2). In the first step of this method the progress percentage scale is spilt for each state in several intervals. The boundary of these states do not overlapped. For this reason, all interval are defined with $[min, max)$ (Design choice 3). The interval is calculated with Metric 1. For state-based views the progress of an interval is defined with the 0-100-Method (Design choice 4). For a non-linear lifecycle the longest path is calculated (Design choice 6). This predicted path can be viewed as a linear path. Additionally, all non-end states are assigned weights manually (with the default value of 3) from $w \in \{1, 5\} \in \mathbb{N}$ (Design choice 7 and 10). For the end state, a weight of zero is assigned automatically. The progress interval of a state can be refined with the consideration of the step-based view. The 0 percent mark is also defined with the creation point in time. Further, 100 percent of a state is defined with the change of the marking from *Activated* into *Confirmed*. Further, an interval for a step is also calculated with Metric 1 (only the variable description change). A single value from the step interval ($[min, max)$) is determined with the 0-100-Method (like a single value of a state). Additionally, as for non-linear state-based views, in a non-linear step-based view the longest path of steps is also calculated and used as a prediction (Design choice 9).

4.4 Research Synthesis

The design choices of the previous discussion are merged into algorithm. To illustrate the algorithm the *Job Offer* process is used. Therefore, each of the four lifecycles of the *Job Offer* process are assigned with weights (on for each state). Further, an active state with the current step is given to calculate the actual progress as an example.

4.4.1 Algorithm

In Algorithm 1 the pseudo-code for the PPD-Method is defined. All design choices of the previous Section are considered and implemented in this Algorithm. To calculated the progress of a lifecycle with the Algorithm ppdMethode(θ^I) a lifecycle process instance θ^I is passed as input. Furthermore, Algorithm 2 is used to determine the progress within the active state. The result of the Algorithm 1 is the current overall progress of the process as a percentage.

A completed lifecycle process instance is not deleted after the the execution, it still exists and one of its end states is marked as *Activated*. For a big business process with a lot of lifecycles there is a point in time of the execution where many lifecycles are in the end state. For performance reasons, the Algorithm 1 is added with an if-statement (line 2), determining whether the active state is an end state. If the active state is an end state the Algorithm returns 100 percent directly.

In case the active state is not an end state the sum of weights of the completed states is calculated (line 5-7). Further, the total weight of the execution path is calculated. In a linear lifecycle the total weight are the sum of all weights (line 9-11). In a non-linear lifecycle the longest path is added with the weight of the active state and the completed weights (line 13). To calculate the longest path, an additional function is called. Since the calculation of the longest path is not the main focus of the PPD-Method, Algorithm 3 is part of the Appendix and it is not be discussed any further. This Algorithm is handed over the set of states and the active state. The result is the path with the maximum sum of weights of the corresponding states. For this reason, it is possible that the Algorithm does not return the longest path (most states), but the path with the most effort (sum of weights). Further, Algorithm 1 implements the Metric 2 (line 14ff). Additionally, the current progress is determined with the minimum of the interval added the progress of the current progress of the active state (line 18). This calculated progress represents the return value of Algorithm 1 (line 19). The current progress of the active state is determined in Algorithm 2 (line 17).

Algorithm 1: ppdMethod(θ^I)

Data: Lifecycle process instance θ^I with an active state σ_A^I and the set of states instances Σ^I

Result: Progress percentage of the lifecycle process instance θ^I

```
1  begin
2      if σ_A^I = end state then                    ▷ Active state = end state
3          return 100
4      else
5          w_completed ← 0
6          foreach σ_k.μ_σ = Confirmed do           ▷ Calculate w_completed
7              w_completed ← w_completed + w_k
8          if P^I = ∅ then                          ▷ Linear lifecycle
9              w_total ← 0
10             foreach w_j ∈ W^I do                 ▷ Calculate w_total
11                 w_total ← w_total + w_j
12         else                                     ▷ Non-linear lifecycle
13             w_total ← longestPath(Σ^I, σ_A^I) + w_completed + w_A
14         size ← 100 * (w_A / w_total)             ▷ Size of the interval
15         min ← 100 * (w_completed / w_total)      ▷ Min progress σ_A
16         max ← 100 * ((w_completed + w_A) / w_total) ▷ Max progress σ_A
17         progressState ← ppdMethodStep(σ_A^I)     ▷ Step PPD
18         progress ← min + size * (progressState / 100)
19         return progress
```

Algorithm 2 calculates the progress of the current state. Therefore, the active state is handed over. The if-statement distinguishes between linear and non-linear paths within the state (line 2). In the first case of linear states, the total number n of steps and the total number of completed steps is evaluated (line 3-4). For the second case, Algorithm 3 is used to determine the predicted execution path within the state. Therefore, the predicted pending steps are calculated (line 6). In line 7, the number of completed steps is determined. A step marked with *Unconfirmed* indicates a step possesses a valid data value and is described as completed steps in the Algorithm. The pending steps and completed steps define the total steps (line 9). Further, the progress of a state is calculated as defined in Metric 1 (with adjustment of the variable of a step of Table 4.3) and the Design choice 9 (line 9-10). Finally, the progress of the state is returned (line 12).

Algorithm 2: ppdMethodStep(σ_A^I)

Data: Active state σ_A^I from the lifecycle process instance with the current step γ_E^I)
Result: Progress percentage of the active state σ_A^I

```
1  begin
2      if P^I = ∅ then                                   ▷ Linear state
3          n_completed ← |σ_A^I.μ_γ = Unconfirmed|
4          n_total ← |Γ^I|
5      else                                              ▷ Non-linear state
6          n_pending ← longestPath(Γ^I, γ_E^I)           ▷ Determine longest path
7          n_completed ← |σ_A^I.μ_γ = Unconfirmed|
8          n_total ← n_pending + n_completed + 1
9      size ← 100/n_total                                ▷ Size of the interval
10     progressState ← (n_completed) * size              ▷ 0-100-Method
11     return progressState
```

4.4.2 Demonstration of the PPD-Method

In the Appendix the lifecycles of the *Job Offer* lifecycle process are given. In this Section, for each of the lifecycles the progress is determined with the PPD-Method as describes in Algorithm 1 and 2. Therefore, a simplified model of each lifecycle including the manually assigned weights for each state is used. Additionally, the current step and its

corresponding active state is given to allow the progress determination for that specific point in time of the execution.

First, the lifecycle *Job Offer*, which is shown in Figure A.1, is considered. In this example, the state *Preparation* is defined as the active state σ_A. In the automatically created form of the *Preparation* lifecycle (shown in Figure 2.4) the *Title* and *Distribution* has to be filled out and the *Category* must be chosen. A model of the *Job Offer* lifecycle with this conditions and the weights are shown in Figure 4.17.

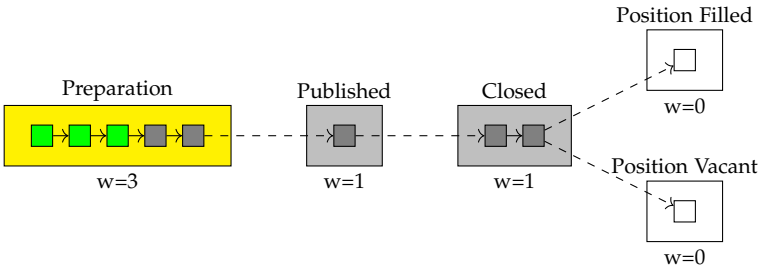


Figure 4.17: Model of the *Job Offer* process from A.1, with active state and current step.

For Algorithm 1 the lifecycle *Job Offer* is handed over as input. The active state is not an end state. Further, there is no state, which is marked as *Confirmed*. This results in the weight of all completed states of zero. In the state *Closed* a decision is made. For this reason, the calculation of the longest path is needed. Therefore, the active state and the set of steps are handled over for the Algorithm 3 (see Appendix). This Algorithm returns $w_{total} = 5$. The size of the interval for the active state is determined and gives a range of 60 percent. This results in a minimum of zero percent and maximum of sixty percent for the active state. Accordingly, the progress of the state is determined. Therefore, Algorithm 2 is called. The active state is a linear one. For this reason, the numbers of steps defines the variable n_{total} (in this case $n_{total} = 5$). Besides, three of the five steps are marked with *Unconfirmed*. It follows $n_{completed} = 3$. The size of a step interval is 20. Lastly, the progress of the active state is calculated with the 0-100-Method and results in 40 percent. This 40 percent is returned. Finally the total progress of lifecycle is determined in the end of Algorithm 1. Therefore, the calculated minimum is added to the progress of a step (depending on the interval size of the active state). The total progress of the lifecycle *Job Offer* with the condition of Figure 4.17 results in a overall progress of 24 percent.

Figure 4.18 *Application lifecycle*, Figure 4.19 *Review lifecycle*, and Figure 4.20 *Interview lifecycle* show further examples of the *Job Offer*. For each of them an active state including the assigned steps is given. For all of these lifecycle process instances the overall progress is calculated using the PPD-Method.

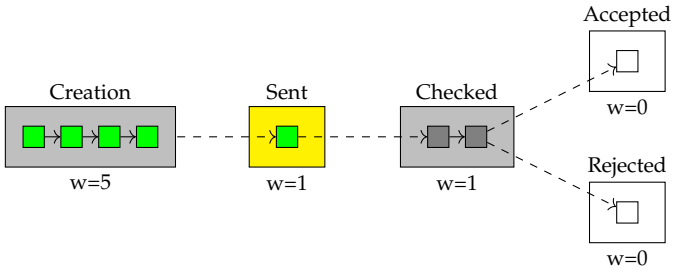


Figure 4.18: Model of the *Application* process from A.2, with active state and current step. Value from Algorithm 1: $w_{completed} = 5$, $w_{total} = 7$, $size = 14.29$, $min = 71.43$ and $max = 85.71$. Value from Algorithm 2: $n_{pending} = 0$, $n_{completed} = 1$, $n_{total} = 1$, $size = 100$ and $progressState = 0$. Result: 71.43

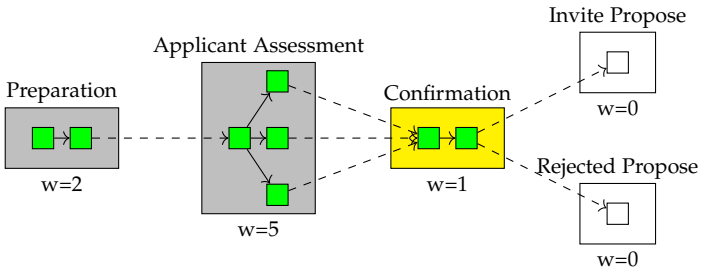


Figure 4.19: Model of the *Review* process from A.3, with active state and current step. Value from Algorithm 1: $w_{completed} = 7$, $w_{total} = 8$, $size = 12.5$, $min = 87.5$ and $max = 100$. Value from Algorithm 2: $n_{pending} = 0$, $n_{completed} = 2$, $n_{total} = 2$, $size = 50$ and $progressState = 0$. Result: 93.75

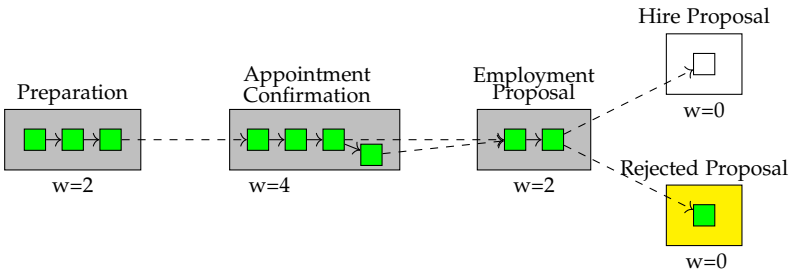


Figure 4.20: Model of the *Interview* process from A.4, with active state and current step. An end state is marked as active. For this reason, the Algorithm 1 returned 100 percent and terminated

5 Summary and Outlook

In this last Chapter, a summary of the results of this thesis is given. This includes the progress calculation of a lifecycle. Additionally, further work of progress determination in an object-aware business process of PHILharmonicFlows is described. For this purpose, additional research options are addressed as well as further improvements.

5.1 Summary

Monitoring in other BPM tools have limited progress determination functionality. Often only the current status can be viewed by consulting the log data and their colouring encoded process model. Progress calculation could not be found in existing BPM tools. For this reason, no benchmark, references, or metrics for progress calculation could be taken over from other BPM tools for PHILharmonicFlows. However, methods from software management to calculate the progress of a project exists. Only the idea of the 0-100-Method to determine progress of an atomic unit (like for a step or state) and the V-Model to structure the research questions could be adopted. In this thesis, the PPD-Method was defined, which uses a fixed snapshot (static consideration) of a object-aware business process taken during execution to determine the current progress. The second part, dynamic consideration of object-aware business process, was not addressed.

For the progress calculation of a lifecycle in PHILharmonicFlows, first the progress of a state-based view (Research question 1) and second the step-based view (Research question 2) was considered. In the first research question, first the 0 percent mark of a lifecycle was defined. This mark was defined with the creation of the lifecycle process instance (Design choice 1). Further, the 100 percent mark was defined with marking an end state as *Activated* (Design choice 2). Each state in a lifecycle process instance was assigned a possible progress interval. In an equally distributed lifecycle, all intervals are

considered to have the same size. The interval boundaries were defined by $[min, max)$ (Design choice 3 and Metric 1). The value *min* and *max* describes the minimum and maximum of the interval. The maximum of the last interval of the execution lifecycle is 100 percent. However, with the right opened interval the 100 percent is excluded in this last interval. By reaching an end state the 100 percent are achieved. To determine a progress only in a state-based view without the step-based view the intervals is broken down to a percentage (Design choice 4). This percentage was defined with the 0-100-Method from software project management. Design choice 5 describes the summary of Design choice 1 to Design choice 4 (according to the research question structure). In a non-linear lifecycle process instance the execution path must be predicted. In this case, the longest path from the active state to an end state is determined (Design choice 6). Additionally, progress calculation of different weights of states were defined. The possible values of weights are: 1 - rapid, 2 - fast, 3 - normal, 4 - slow and 5 - sluggish. All end states are assigned with a weight of zero. A weight of zero is only allowed for end states. The default value is normal (3) (Design choice 7). Metric 1 was adapted to weighted states in Metric 2. The resulting Design choice 8 specifies the summary of Research question 1 according to the V-Model structure. Furthermore, Research question 2 was used to refine the progress calculation of state-based view in its lifecycle process instance. First, all design choices of the Research question 1 were considered as a design choice to determine progress in a step-based view of a state. The 0 percent mark of a state is the same as the 0 percent of the lifecycle process instance. Furthermore, no empty end step exists in a state. For this reason, an other option for the 100 percent mark of a state was defined. This point is specified with the change from the *Activated* to *Confirmed* marking of the corresponding state. The boundaries of a step interval is calculated with the same metric as the boundaries of a state interval. An atomic unit of a state is a step. The progress of one step is determined with the 0-100-Method. Finally, for a non-linear state the longest execution path is predicted. All this was defined in Design choice 9. In the last research question, methods to assign weights of a state were discussed. Therefore, manual allocation of weights is an option and the calculation of the number of steps describes the alternative option to determine the weight of a state. In this case, both options were defined in Design choice 10. Automatic determination of weights can be improved with the manually one. Finally, the end of the V-Model was described with the summary of all design choices and summarised in Design choice 11.

On the whole, the results of the design choices were implemented in several Algorithms. First, Algorithm 1 is handed over a lifecycle process instance with an active state. The Algorithm returns the progress percentage of this lifecycle process instance. Therefore, the Algorithm calculates the state interval and calls Algorithm 2 to determine the progress of the active state. This second Algorithm returns the progress of the active state. At the end, the first Algorithm calculates the current overall progress of the lifecycle process instance by combining the state interval and the handed over state progress.

5.2 Outlook

In general, this thesis covers only a small part of a big research field. First, Research questions 3 and 4 from the primary research question, which are introduced in Section 4.1 must be discussed in further works. Secondly, dynamic consideration of object-aware business processes should be addressed. Thirdly, the calculation of progress can be supplemented and improved with machine learning or probability models. The following Section gives a short overview of each of this research possibilities. Even more advanced research based on this thesis is now possible, even though not explicitly stated.

Research question 3 describes the combination of lifecycles with: *How can the progress of multiple, different lifecycles with relations be determined?* In this thesis, each lifecycle is considered separately. In Figure 4.1, the process dependency structure of process lifecycle instances is shown. Research question 3 discusses how a total progress of all lifecycle process instances can be determined. In the *Job Offer* example, all lifecycles have the same structure. They have three states and in the last of this three state a decision is made. This decision step has two possible paths. Each of them consists of only one state, an end state. However, in the process dependency structure there are big lifecycles and smaller ones. This research question discusses how total progress of the business process with multiple different lifecycles is possible. Possible options for this are for example, each lifecycle can be weighted manually or automatically based in their number of states. Further, each state of the business process can be viewed without the consideration of a lifecycle and its state-based view. These options must be discussed in further works.

Research question 4 describes the additional structure of a coordination process with: *How does a coordination process affect the progress of an object-aware business process?* Therefore, Figure 4.1 can be viewed again. There, the coordination processes are displayed (see [6] for more information about coordination processes). One focus of this research question could be the evaluation of possible improvements with coordination processes.

Furthermore, based on the static determination, the dynamic aspects of progress execution can be incorporated into the progress determination, such as instantiation of an process instances or deletion of process instances. Additionally, backwards transition instances of a lifecycle should be discussed in the future. These allow the user to go back in the form to improve and change entered data.

Mainly the efforts of a state is not filling out a form, but on the information procurement to filling out the state. For example, the result of a meeting is recorded in form. The meeting needs three hours, but filling out the form takes only five minutes. For this reason, each state can be divided into a preparation phase and a filling out phase. The second phase can be determined as discussed in Research question 2. However, the

preparation phase is needing a new concept to determine the progress, because no fix points at object-aware business process like the graph-based view of this thesis exists. For this example, machine learning or probability models should be considered and evaluated to allow a prediction of effort for these phases. Further, a distribution between this two phases should be discussed.

Additionally, different presentation possibilities can be discussed. One of the possibilities can be the sunburst diagram from Section 3.3.3. All lifecycles can be structured with their (semantic) relations. In the *Job Offer* example the lifecycle *Job Offer* represents the inner ring of the sunburst diagram, the lifecycle *Application* the middle ring and the lifecycles *Interview* and *Review* the outermost ring. The advantages and disadvantages as well as the suitability of this and other representations should be evaluated in further work.

In summary, the progress determination of the total object-aware business process in real-time offers many more question for research. Beside the progress determination further features (e.g. alarms for exceeded time of filling out a form) of monitoring in object-aware business processes can be discussed. This thesis defines the necessary basics and conditions for these and other research questions for progress determination in object-aware business processes thus enabling new possibilities for a more efficient and productive operation with tools like PHILharmonicFlows.

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A Appendix

A.1 Lifecycle: Job Offer process

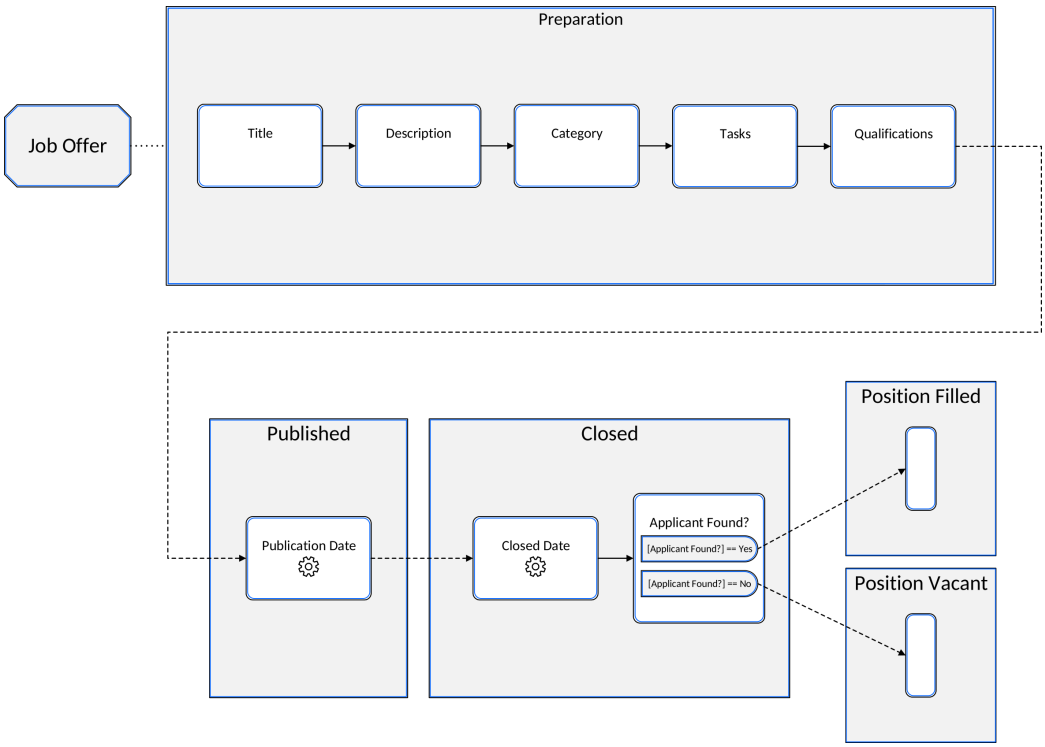

Figure A.1: Lifecycle: Job Offer

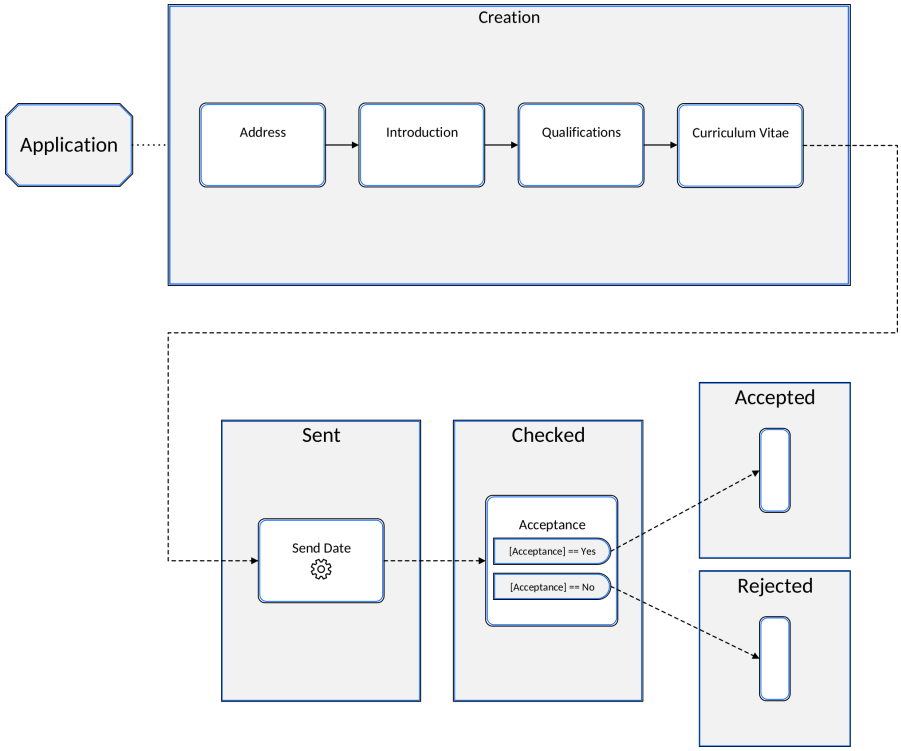

Figure A.2: Lifecycle: Application

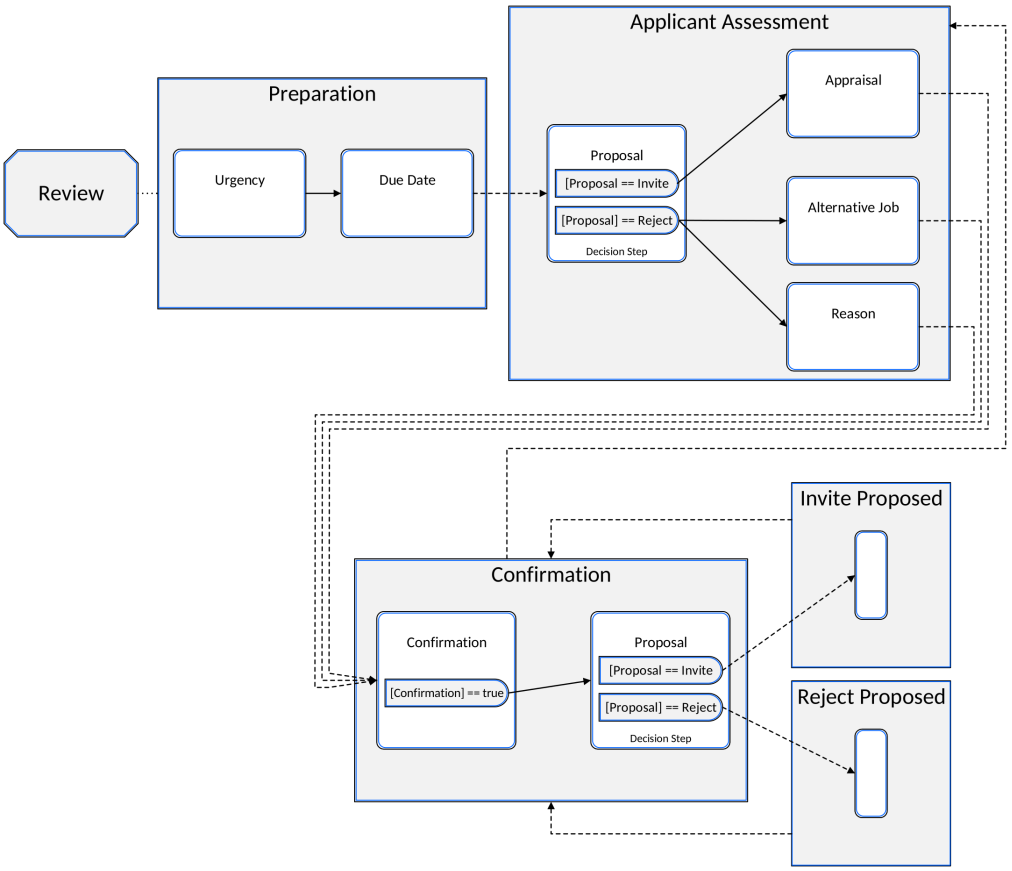

Figure A.3: Lifecycle: Review

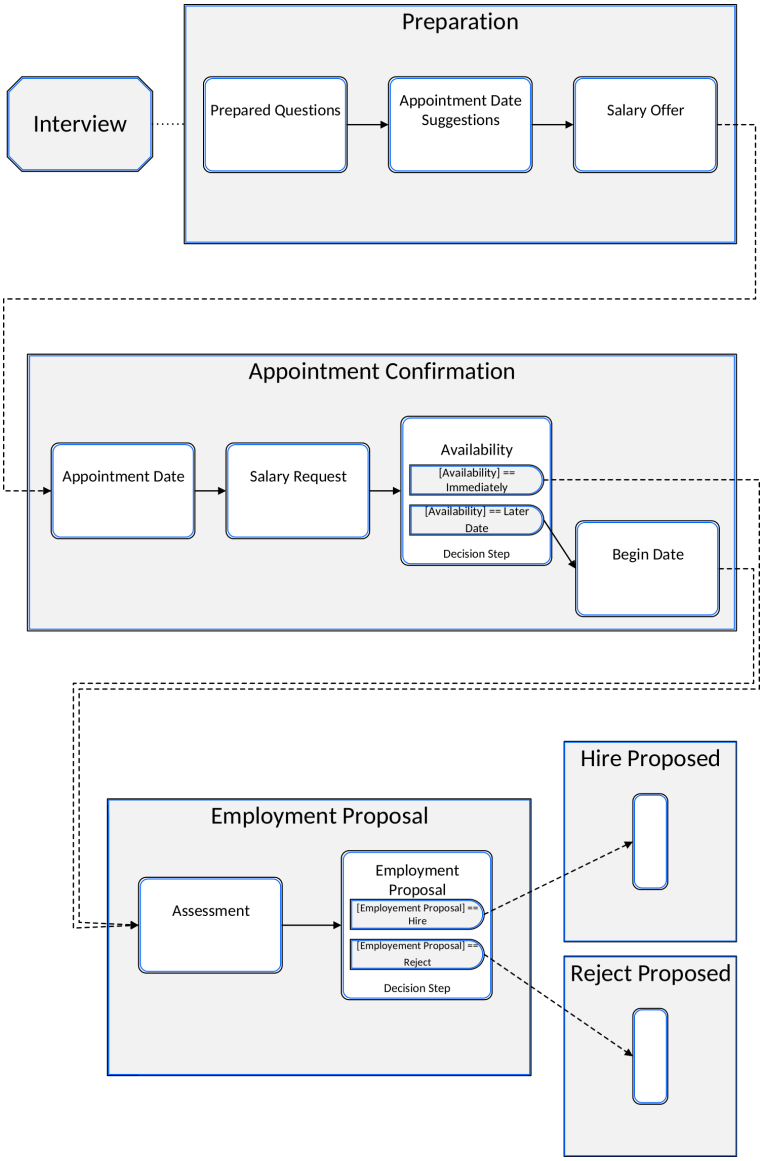

Figure A.4: Lifecycle: Interview

A.2 Markings of a state in object-aware business process

State marking μ_σ	Description
Waiting	The state has not been executed yet. A predecessor state is activated. Before: - After: Pending, Activated, Skipped
Pending	The activation of a state is blocked by an unfulfilled coordination constraint. Before: Waiting After: Activated
Activated	The state is currently executed. Before: Waiting, Pending After: Confirmed
Confirmed	The state has been successfully executed. A successor state is activated. Before: Activated After: -
Skipped	The state can no longer be executed. A state on an alternative branch is activated. Before: Waiting After: -

Table A.1: State marking are used for the execution of a lifecycle in a object-aware business process [6]

A.3 Markings of a step in object-aware business process

Step data marking μ_γ	Description
Waiting	Standardmarking. After instantiation, a step has this marking. All steps in an inactive state have this marking. May reappear after other markings (Activated, Confirmed), if a Backward transition is used. Before: - After: Ready, Enabled
Ready	Marking only occurs in the active state and signals that enabling is possible. By decision (decision step, diverging transitions), marking *Bypassed* is also possible. Before: Waiting After: Enabled, Bypassed
Enabled	The step actively requests a value for its attribute (Request Execution event) Before: Waiting, Ready After: Activated, Blocked, Bypassed
Activated	A value for the step is available (depends on data marking *Assigned* and *Preallocated*). For decision steps at least one predicate step must be marked as *Activated*. Further, a value for the attribute must be present. Before: Enabled, Blocked After: Unconfirmed
Blocked	Decision steps only. Occurs if all steps are marked as *Bypassed* or none are *Activated*. Before: Enabled, Ready After: Activated, Blocked, Bypassed

Step data marking μ_γ	Description
Unconfirmed	After the activation of a step there is still processing necessary for the incoming and outgoing transition. When the step is finished, the step is marked as *Unconfirmed*. Step is in the active state. This marking indicates a step possesses a valid data value and waits for the confirmation of the state as whole Before: Activated After: Waiting, Ready, Confirmed
Confirmed	When leaving (Confirm) a state all unconfirmed steps are marked as *confirmed*. Occurs only with completed states. Before: Unconfirmed After: Waiting, Ready, Enabled, -
Bypassed	Marking for steps on an unused paths within the active state. Signifies a value for the corresponding attribute is no longer needed. Before: Waiting, Ready, Enabled After: Enabled, Ready, Skipped
Skipped	When leaving a state (Confirmd) all bypassed steps are marked as skipped. Occurs only when a state is closed. Before: Bypassed After: Waiting, Ready, Enabled, -

Table A.2: Step data marking, indicate the status of the entity (step) and its change represents the process execution

Data marking d_γ	Description
Unassigned	Attribute of the step has no value. Request event is thrown if, step marking *Enabling*.
DataRequested	Execution Rule related: value was requested
DataPending	Execution Rule related: value was entered. Used for post processing
Preallocated	Attribute has been given a value without a request event going out. If the step is still *Enabled*, the data marking changes to *Assigned* and the step is activated directly, without execution
Assigned	Step has a value and all execution events were processed correctly
Confirmable	Occurs after backward transitions at steps in an active state whose data marking was previously assigned and are confirmed now. Instead of requiring a new value, the old one must be confirmed or replaced if necessary.
ConfirmRequested	Execution Rule related: see *Confirmable*. Analogue *DataRequested*
ConfirmPending	Execution Rule related: see *Confirmable*. Analogue *DataRequested*
DataValueDeleted	Temporary marking for post processing after deleted value. After post processing marking will change to *Unassigned*.
DataValueDeleted	Related to Data Validation, see Marking *Blocked*

Table A.3: Data Markings: indicate the status of the attribute associated with the step

A.4 Algorithm for longest path determination

Algorithm 3: longestPath(Σ^I, σ_A^I)

Data: Set of states Σ^I, active state σ_A^I and a topological sorting (Algorithm 4) of the states to calculate all possible path from the active state to the end states.

Result: Longest (weighted) path of a lifecycle from an active state to an end state

```
1  begin
2      for i ← 1 to |Σ^I| do                                  ▷ Initialise dist[i]
3          dist[i] ← −∞
4      dist[σ_A^I] ← 0                                        ▷ Initialise distance
5      i ← 1
6      topSort ← topSorting(Σ^I)          ▷ Topological sorting (Algorithm 4)
7      while topSort^{-1}(i) ≠ σ_A^I do                       ▷ Find active state at
8          i ← i + 1
9      while 0 ≤ i ≤ n && dist[topSort^{-1}(i)] ≠ −∞ do
10         σ^I ← topSort^{-1}(i)
11         forall σ^I.next of σ^I do                          ▷ For all following states
12             dist[σ^I.next] ← max{dist[σ^I] + w_{σ^I}, dist[σ^I.next]}
13         i ← i − 1
14     longestpath = max{dist[1..|Σ^I|]}
15     return longestpath
```

Note. Change the set of states Σ^I with the set of steps Γ^I and the active state σ_A^I with the current step γ_E^I (marked as *Enabled*) for the longest path of within a state. In a step no weights exists. For this reason the $+ w_{\sigma^I}$ of line 12 will be replaces with $+1$

Algorithm 4: topSorting(Σ^I)

Data: A set of states $\sigma^I \in \Sigma^I$ from lifecycle process instance θ^I (with step $\sigma^I.pre$ as predecessors and $\sigma^I.suc$ as successor of step of step σ^I)
Result: List of topological sorting *topSort* of all states of one lifecycle progress instance θ^I

```
1  begin
2      topSort ← empty list
3      stack ← empty stack
4      in ← dictionary mapping all state to 0
5      foreach σ^I ∈ Σ^I do                                  ▷ Initialize in
6          foreach σ^I.pre adjacent to σ^I do
7              increment in[σ^I]
8      foreach σ^I ∈ Σ^I do                                  ▷ Initialize stack
9          if in[σ^I] = 0 then
10             add σ^I → stack
11     while stack is not empty do                           ▷ Main loop
12         σ^I ← stack.remove
13         append σ^I to topSort                  ▷ Get next step of the TOPSORT
14         foreach σ^I.suc adjacent to σ^I do          ▷ Update in and stack
15             decrement in[σ^I.suc]
16             if in[σ^I.suc] = 0 then
17                 add σ^I.suc to stack
18     return topSort
```

Note. Change the set of states Σ^I with the set of steps Γ^I for the topological sorting of steps in a state.

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Declaration

I, B.Sc. Lisa Arnold, matriculation number 857738, declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research. Furthermore, I have not used any sources or resources other than those specified.

Ulm, ...

B.Sc. Lisa Arnold