# POWER2DM

**"Predictive model-based decision support for diabetes patient empowerment"**

**Research and Innovation Project**
**PHC 28 – 2015: Self-management of health and disease and decision support systems based on predictive computer modelling used by the patient him or herself**

## POWER2DM D3.3 (or D3.2.1a)

## Recommender Engine

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|---|---|
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| **Dissemination Level** | | |
| **PU** | Public | X |
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| **RE** | Restricted to a group specified by the consortium (including the Commission Services) | |
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|---|---|---|
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| IDK | Institute of Diabetes "Gerhardt Katsch" Karlsburg | Germany |
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| LUMC | Leiden University Medical Center | Netherlands |
| SAS | SAS Servicio Andaluz de Salud | Spain |
| SRFG | Salzburg Research Forschungs Gesellschaft | Austria |
| PD | PrimeData | Netherlands |
| iHealth | iHealth EU | France |

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# 1 Introduction

## 1.1 Purpose and Scope

The purpose of deliverable D3.3 is to provide the software implementation and demonstrator for POWER2DM Communication Engine. This document provides an implementation report illustrating its architecture, functionalities and demonstration setup showing how it is used.

IMPORTANT NOTE: The consortium decided to rename the Recommender Engine component as Communication Engine within the project as it is more suitable with the functionality.

## 1.2 References

- D1.2 Requirement Analysis of POWER2DM
- D1.3 Conceptual Design of POWER2DM
- D3.1 Dynamic Health Behaviour Change Intervention Models for Self-management
- D4.1 Personal Data Model and Service API

# 2 Approach and Architecture

## 2.1 Approach for Intervention Delivery

The objective of Communication Engine is to **monitor patient's daily actions and measurements**, by considering his goals and action plans, and **help him/her** when necessary by **initiating a communication**. This communication is in fact a psychological or medical digital intervention aiming to motivate, warn, remind patient or make him provide further information regarding a problem/barrier. Different communication mediums can be used, but in POWER2DM, we will use POWER2DM Mobile Application and use the push notifications to initiate these communications. Therefore, the main functionality of Communication Engine is to decide the timing and content of intervention and trigger the initiation (this time it is push notification but can be SMS or email, etc.).

The concept of dynamically adapting the timing and content of intervention is called Just-In-Time Adaptive Intervention (JITAI) and described in D3.1. Here, in this deliverable, we describe our implementation approach to perform this dynamic adaptation and personalization. However, before that, we need to summarize the POWER2DM intervention approach in this context.

In general, we categorize the interventions in POWER2DM in terms of delivery methodology;

- Ones (JITAIs) to be delivered within the day as a daily support via Mobile Application (initiated by Communication Engine)
- Ones to be delivered periodically for the evaluation of patient's performance via the POWER2DM Web Application (Action Plan Engine) where patient is expected to initiate the session as defined in the care program (weekly or biweekly)

Communication Engine only deals with the first one and it has two aims;

- help patient to adhere his action plans that is **obtain or preserve the healthy behaviour change** e.g. attaining the requested blood glucose monitoring behaviour, increasing physical activity, etc.
- **instruct patient for probable future (predicted) bad situations to prevent them** e.g. "You made an extra-long walk this afternoon, beware about your insulin sensitivity in the next hours"

In this respect, we have the following categorization for purpose of intervention;

- **After Event Motivation:** These are interventions for the first objective above and be delivered to motivate patient either after a performed action or daily performance or after a missed action.
  - e.g. "That was a good day! You walked 10% more than yesterday."
  - e.g. "You made so much progress this week! This was not your best day, but you worked hard, this week!"

- **Motivation with Reminders:** Also for the first objective, these are the interventions to be delivered before a planned action to remind and motivate the patient to do it.
  - e.g. "You have a scheduled BG monitoring after dinner and you are almost there! Keep on adhering your schedule and you will reach your goal this week."

- **Preventive Interventions:** These interventions are for the second objective and delivered when some event is possible according to clinical guidelines or predictive models and warning/instruction patient may be useful.

As you see from the examples, each of these interventions has different **decision points** in time. For After Event Motivation and Preventive Interventions, the point is after a performed action or measurement (which can be a passive measurement without act of patient like Fitbit data) or a completion of all actions for the day. For reminders, it should be before the scheduled action.

After identifying the decision points, another crucial point is to take the decision whether the intervention is required/desired or not, the **decision rules** component of JITAIs. A multidisciplinary discussion among consortium identifies four issues for decision rules;

- Decision should be in line with **clinical evidence regarding diabetes**; for clinical safety
- Decision should be in line with **health behaviour change theories**, so that they can be effective
- Decision should be in line with **patient's preferences;** because we don't want patient to stop using the application, increase the burden on him with too many messages or the ones that he/she does not like
- Decision should be in line with the **treatment plan** set by the physician for the patient; because it gives us the main objective of self-management period; the medical problem (e.g. too little glucose monitoring), the goal (e.g. 3 times a day) and planned actions (e.g. monitor your BG after breakfast, etc.) to solve the problem.

For the first prototype, which is also scope of this deliverable, it is decided to focus on reminders and after event motivations, in other words focus on behaviour change. It is also decided to take patient's preferences and treatment plan as the major factor for deciding to deliver the intervention or not as a first step.

Therefore, for the first prototype, the decision mechanism will be as follows;

Interventions will be delivered only for patients' related treatment or self-management active goals and action plans set by physician or patient thyself. So, if patient does not have a goal regarding physical activity for that period, no intervention will be delivered related with physical activity.

Interventions will be delivered based on patients' preferences for that specific goal and the intervention type (e.g. reminder, etc.). The following is the possible preferences;

- **Each Time (Always):** For <u>each planned action</u> for a specific time the intervention will be delivered. e.g. If patient select "mandatory" for "reminders" for "BG monitoring goal", a reminder will be sent for each planned action (once after breakfast, once after lunch, etc.).
- **Frequently:** The intervention will be delivered <u>at least once within a day</u> that an action is planned. e.g. If patient select "Highly Preferred" for "motivations" for "BG monitoring goal",

a motivation message will be sent either at the end of the day or after a performed or missed action.
- **Occasionally:** The intervention will be delivered at least once within a week for any day that action is planned.
- **Rarely:** The intervention will be delivered at least once within a month for any day that action is planned.
- **Never:** The intervention will never be sent.

In the second prototype, we will improve the mechanism by also basing the decision on latest performance of patient on the behaviour. e.g. If patient is not good at behaviour, we may increase the number of interventions.

Next step is to decide the intervention type and content. From the behaviour change (psychological) perspective there are different intervention types and Behavioural Change Techniques (BCTs). Some of them considered in POWER2DM are as follows which will be described in D3.1 and D3.2;
- Positive comparison with self
- Positive comparison with others
- General reinforcement
- Social support
- Anticipatory coping
- Planning and goal setting
- Giving feedback about goals

Each of them can be used in different purposes (e.g. as reminder or after event motivation) with different contents according the patient context; patient's latest performance(s) regarding his goal. Basic categorization of context is as follows;
- Achieved more than goal
- Achieved the goal
- Almost achieved the goal
- Achieved less than goal

As easily concluded, each goal type has its internal logic for the evaluation the actual data to decide on this context; e.g. What does it mean if patient has missed a BG monitoring action among 3 within a day as well as the different timelines that the goal is evaluated (e.g. a single action, daily, weekly, monthly).

For the first prototype, our approach for the selection of intervention type and then content is as follows;
- Randomly select the intervention technique among the available ones for the specific goal (T3.1 provides us the list of intervention templates providing a specific BCT technique for each goal type for each context).
- Resolve the context of the patient from the latest and past data and choose the intervention content accordingly.
    - e.g. Context: "Achieved less than goal" and BCT:"Positive comparison with self" → Find some positive comparison for patient to state that "'You made so much progress this week, %10 more than last week! This was not your best day, but you worked hard, this week!'"

The next sections will describe how we implement these decision points and decision rules.

## 2.2 Architecture and Technologies Used

The approach described in the Section 2.1, enforce several technical requirements for Communication Engine; need continuous monitoring of actions, need to run specific tasks for several decision points and for different time periods, etc. Moreover, this should be done for all patients which needs scaling up of the system if number of patients increases.

We have decided to go with Reactive Programming paradigm by using existing technologies in this context to perform these tasks in a distributed and effective way. We use the following technologies;

- Apache Spark and Spark Streaming for distributed processing
- Apache Kafka for publish/subscribe mechanism between PDS and Communication Engine to monitor the new observations and actions
- Akka.io to setup a distributed actor based Complex Event Processing (CEP) environment
- Cassandra for temporarily persisting patient state

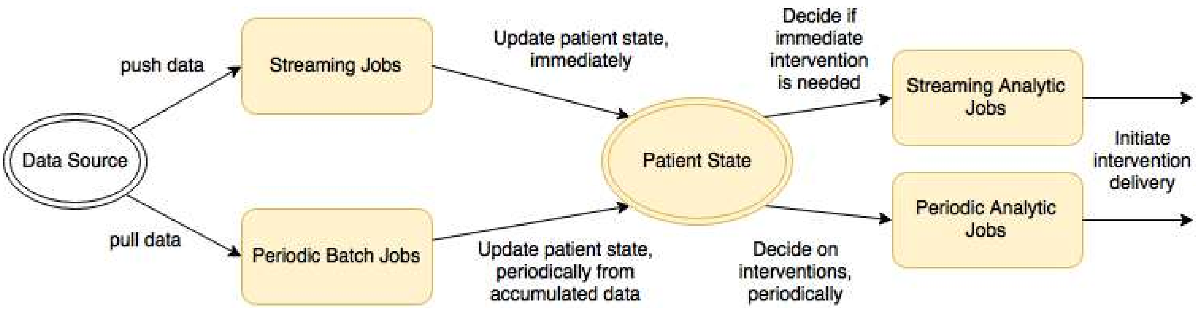



**Figure 1 Implementation Approach for Communication Engine**

In general, our implementation approach follows the Lambda architecture which is a data-processing architecture designed to handle massive quantities of data by taking advantage of both batch- and stream-processing methods. Figure 1 illustrates the basic approach. The "Data Source" is POWER2DM Personal Data Store in our case and it stores all the data collected in POWER2DM.

We process the data in two layers; "Batch Layer" and "Speed Layer (Streaming)" which is the main characteristics of Lambda architecture. In batch layer, we generally run jobs daily to process the data of all patients and update their patient state. And we do this mostly for data that is not changed frequently like POWER2DM Goal, ActionPlans, MedicationOrders, CommunicationPreference, UserSettings resources (Please see D4.1 for the description and content of these resources). The streaming jobs handle the data that we need continuous monitoring to update patient state immediately and react immediately. This type of data is the POWER2DM Observations and MedicationAdministrations e.g. BG measurement, insulin intake log, dietary intake log, etc.

On the other side, similarly we decide on interventions in two ways. In batch layer, the decision will be taken periodically for a specific period e.g. every 20 minutes analysing if there is a reminder scheduled within this period and send it. The streaming layer reacts significant changes in Patient State and decide if an intervention is needed e.g. Patient has a heavy exercise session, KADIS predicts a possible hypoglycaemia and patient needs to be warned.

Figure 2 illustrates the architecture and sub modules of Communication Engine component. As shown, it gets patient data from POWER2DM PDS via its FHIR Rest API (pull based) and via Apache Kafka by subscribing certain topics and get the data as continuous stream. The followings are the summary of functionalities for each sub-module;

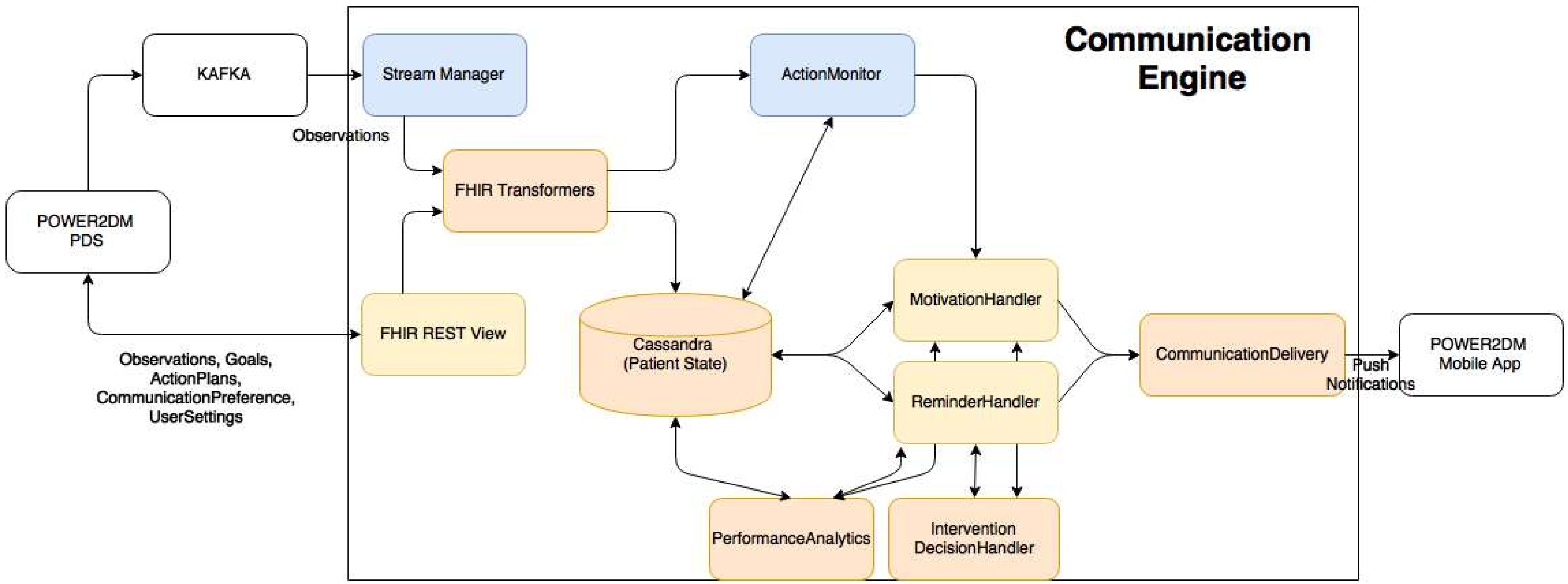



**Figure 2 Internal Architecture of Communication Engine**

- **FHIR Rest View:** Component that calls the PDS FHIR Rest API to retrieve data in FHIR resource format.
- **Stream Manager:** It subscribes to certain POWER2DM resources in Kafka and creates a Spark Stream from them and runs the transformers to transform them to update patient state.
- **FHIR Transformers:** They transform POWER2DM resources in FHIR format into the internal data model to form/update the patient state.
- **Internal Data Model (Patient State) and Persistency (Cassandra):** Provides the data model descriptions and persistency mechanism for them to represent patient state which is the common model for all other modules that try to decide regarding intervention delivery.
- **ActionMonitor:** Monitors the latest observations from the stream of observations created by StreamManager and match them with the schedule actions and update the patient state accordingly. e.g. A new BG measurement will update a scheduled BG monitoring action as performed with the details like action time, etc.
- **ReminderHandler:**
    - Every day (at the end of the day), evaluate the planned actions for the next day, and decide on the reminders for the next day based on patients' preferences and action plans and write these reminder schedules to patient state.
    - Periodically (e.g. every 10 minutes), check the scheduled reminders and schedule an intervention delivery in CommunicationDelivery component if reminder is still valid (action is not performed yet).
- **MotivationHandler:** In general, it handles the "After Event Motivation" interventions;
    - Periodically, evaluate the missed actions (scheduled but not performed) in the past in a specific period and manage the intervention decision and schedule the deliveries.
    - Monitor the performed actions stream generated by the ActionMonitor and manage the intervention decision for them and schedule the deliveries.
- **InterventionDecisionHandler:** Module used by ReminderHandler and MotivationHandler to decide on the intervention type (e.g. positive comparison with self vs social support) and timing of intervention.
- **PerformanceAnalytics:** Module used by ReminderHandler and MotivationHandler to get the analytic results related with intervention content. e.g. Social comparison with self → Find a positive comparison to show to the patient
- **CommunicationDelivery:** Retrieve the intervention schedules and perform the deliveries by sending the push notifications.

Implementing these components as Spark and Spark Streaming tasks enables effective distributed processing where system can be scaled up as much as required based on number of patients.

## 2.3 Internal Data Model (Patient State) and Persistency

Figure 3 illustrates the data entities that a patient state is composed of. As persistency is handled by using Cassandra, we have mark the keys in the Cassandra terminology;

- PK is the partition key
- CK is the clustering key
- and other fields

The PatientState in the middle is abstract so there is no such persisted collection but it is composed of all other entities belonging to same patient.

**PatientMetric** is the entity that represents a metric related with patient's health. It can represent a single measurement like BG value at specific time instant or represent some average (or other result of another analytic procedure) in a specific period like average BG last week, or percentage of abnormal BG measurements, etc.

- pid → Patient identifier (pseudonym identifier from PDS)
- period → The periodic category for the metric (0: Instant, 1: Daily, 2: Weekly, …)

- metric → The identifier for the metric e.g. BG for blood glucose measurement
- ts → Time or (starting time of the period) of this metric
- tsEnd: If metric is periodic, the end time of the period
- value: Value of the metric e.g. BG value
- context: Other data related with the metric if any
- rid: FHIR resource id in PDS related with this record (only for instant measurements)

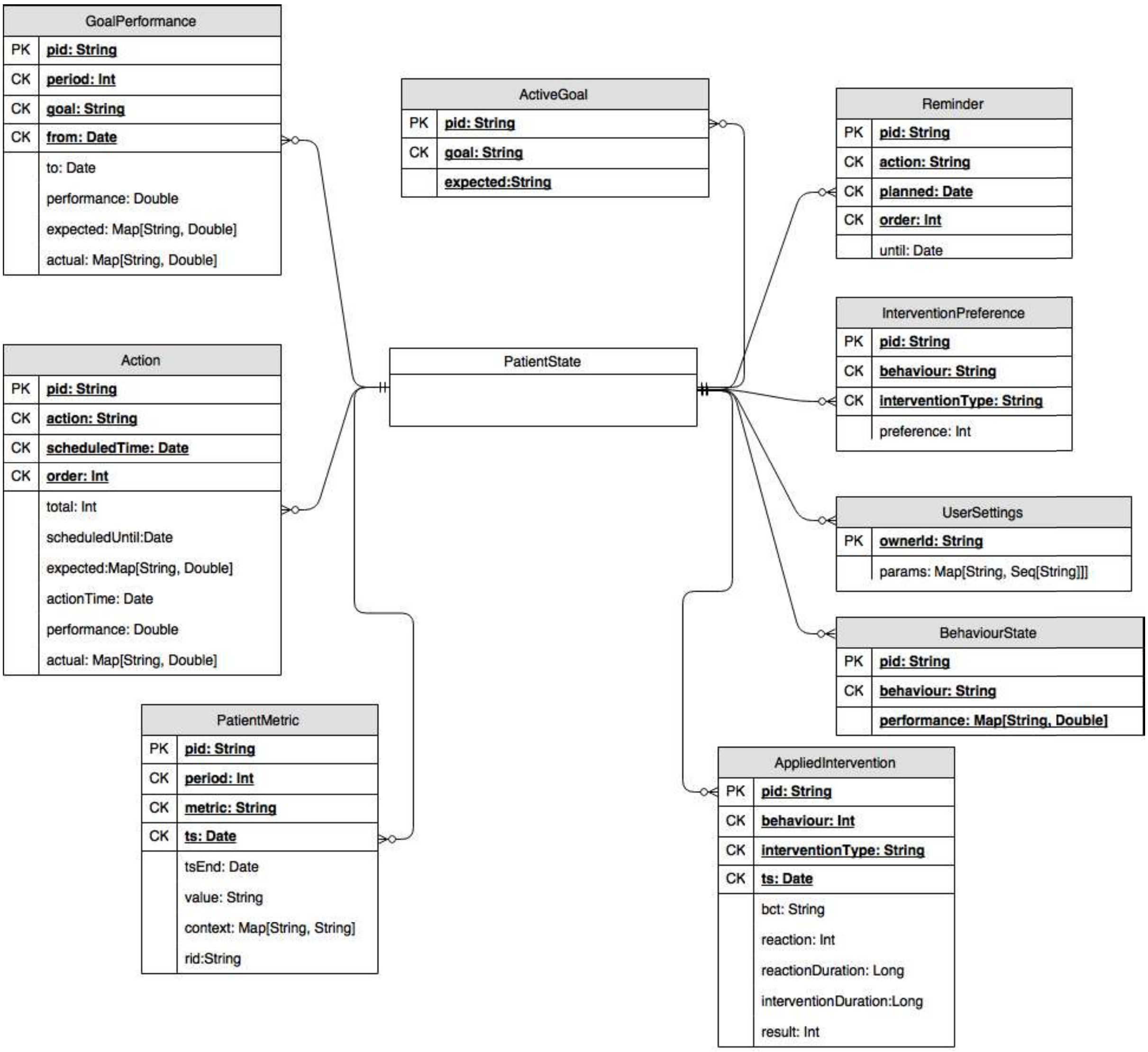



**Figure 3 Internal Data Model (Patient State)**

**Action** represents a scheduled action for a specific time instant or a period. If it is performed, it also contains data about the performed action (time of performance, etc.) as well as the calculated performance regarding with the behaviour. e.g. Insulin adherence performance can be calculated based on the comparison of scheduled and performed dosage as well as the timing adherence.

- pid → Patient identifier (pseudonym identifier from PDS)
- action → Identifier for the action e.g. bg-monitoring
- scheduledTime → Scheduled time instant (or starting of the period) for the action
- order → An POWER2DM ActionPlan may state more than one scheduled instant points in the given period (day or week). This attribute states the order within all these scheduled instant points. e.g. ActionPlan: BG monitoring 3 times a day
- total → Total number of scheduled instant points for the same action (See order)

- scheduledUntil → The end time of the scheduled period if it is a periodic schedule e.g. 3 walking sessions within a week
- expected → Expected characteristics of a planned action e.g. 1 hour walking
- actionTime →If this scheduled action is performed, shows the performance time
- performance → Calculated performance point (percentage) for this scheduled action instance
- actual → Actual characteristics of the performed action e.g. 45 min walking (For comparison with expected)

**ActiveGoal** represents the active goal set for a patient for a specific behaviour or metric
- pid → Patient identifier (pseudonym identifier from PDS)
- goal →Identifier for the goal (same as action identifier for behavioural goals) e.g. bg-monitoring
- expected → Expected characteristics of the goal e.g. 3 BG monitoring on average for each day
- from →Starting time of the goal
- until → Time until the goal is valid (or should be valid)

**GoalPerformance** represents the performance of a patient for his/her specific goal for a specific period (daily, weekly, etc.). It is calculated from the Action records based on the action performances.
- pid → Patient identifier (pseudonym identifier from PDS)
- period → The periodic category for the goal (1: Daily, 2: Weekly, …)
- goal →Identifier for the goal (same as action identifier for behavioural goals) e.g. bg-monitoring
- from → Starting time of the period that this evaluation is about
- to →End time of the period that this evaluation is about
- performance → Calculated performance point (percentage) for the evaluation of how well patient reaches his goal
- expected → Expected characteristics of the goal e.g. 3 BG monitoring on average for each day
- actual → Actual performed characteristics of the goal e.g. 2.6 BG monitoring on average for each day

**AppliedIntervention** represents an applied intervention to a patient including the behaviour that intervention is about and the type of intervention and collected reaction data from the patient regarding intervention.
- pid → Patient identifier (pseudonym identifier from PDS)
- behaviour → Behaviour (action) identifier that this intervention is about e.g. bg-monitoring
- interventionType → Type of intervention delivered e.g. Reminder
- ts → Time of intervention delivery
- bct → Main Behavioural Change Technique used for the intervention e.g. social comparison with self
- reaction → Patient feedback; Is reacted by the patient? (Not implemented yet)
- reactionDuration → Patient feedback; Minutes passed to react by the patient? (Not implemented yet)
- interventionDuration → Patient feedback; Minutes passed during the intervention? (Not implemented yet)
- result → Result indicator of the intervention. (Not implemented yet)

**UserSettings** represents the user settings for patient.
- ownerId → Patient identifier (pseudonym identifier from PDS)
- params → Setting parameter map

**InterventionPreference** represents a patient's preference regarding a behaviour and intervention type. e.g. For BG Monitoring for "Reminders" …

- pid → Patient identifier (pseudonym identifier from PDS)
- behaviour → Behaviour (action) identifier that this intervention preference is about
- interventionType → Type of intervention that this preference is about
- preference → Preference indicator (0: Never --- 5: Always)

**Reminder** represents a scheduled reminder for the next day for a patient for a specific action

- pid → Patient identifier (pseudonym identifier from PDS)
- action →Action identifier for this reminder is about
- planned → Planned time for the reminder
- order → Order of the scheduled action that this reminder is about
- until → The time that this reminder is valid until

**BehaviourState** represents the performance state of a patient for a behaviour;

- pid → Patient identifier (pseudonym identifier from PDS)
- behaviour → Identifier for this behaviour (same as action ids)
- performance → Several performance results as map. Keys can be
    - ltp: Performance of last scheduled day for behaviour
    - rp: Recent performances (recent depends the type of behaviour)
    - twp: Performance within the current week (Monday-Sunday)
    - lwp: Performance within the last week (Monday-Sunday)
    - t2wp: Performance within the current 2-week period
    - l2wp: Performance within the last 2-week period
    - tmp: Performance within current month e.g. October
    - lmp: Performance within last month
    - t3mp: Performance within current 3-month
    - l3mp: Performance within last 3-month
    - bp: Best performance ever
    - wp: Worst performance ever

## 2.4 Transforming FHIR resources to Internal Model

For each data entity in the internal model, we have a transformer that process the corresponding POWER2DM resource(s) (FHIR content format) and transform it to one or more records and update the patients' states.

As described previously, FHIRRestView module retrieve the data and initiates the transformations every day (at the end of the day) to prepare for the next day

- **POWER2DM Goal** resources that are still active are transformed to **ActiveGoal** records; active goals of patients (overwriting previous records)
- **POWER2DM InterventionPreference** resources are transformed to **InterventionPreference** records; latest preferences of patients (overwriting previous records)
- **POWER2DM UserSetting** resources are transformed to **UserSetting** records; latest user settings of patients (overwriting previous records)
- **POWER2DM ActionPlan** resources that schedules something for that day are transformed to **Action** records; schedules for specific time within the day + schedules for unspecified time (but is scheduled for the day)
- **POWER2DM MedicationOrder** resources that schedules medications for that day are transformed to **Action** records

FHIRRestView module provides the necessary FHIR query mechanism to retrieve those specific records as described above. In addition, it provides a mechanism, to make these queries in a distributed way to exploit the distributed processing functionalities provided by Apache Spark environment. It basically distributes the query to available Spark Executors evenly by using the paging mechanism of FHIR search operation (Each executor performs the same query with a different paging number).

ActionPlan conversion is more complex than others as in an ActionPlan resource there are three different scheduling mechanisms. The idea is to have only the planned actions for the next day within the patient state. Different scheduling mechanisms are as follows;

- Scheduled with exact times for specific days (e.g. Walk on Monday, Wednesday, Friday at 18:30) → Transformed to Action records for the next day for each specific time by assigning an order to them (this time once at 18:30) if the action is scheduled for the next day (if next day is Monday, Wednesday or Friday)
- Scheduled with relative times for specific days (e.g. Monitor your BG every day 30 min after breakfast, lunch, dinner) → Transformed to Action records for the next day by calculating the approximate time based on the UserSettings (general timing of daily events like breakfast)
- Scheduled for a period with specific frequency (e.g. 1 hour walking 3 times a week) → Check the remaining actions for the period and schedules them for the next day if the period includes the day by assigning an order to them

Apart from these, the transformer for the POWER2DM Observation resources that transform them to PatientMetric runs on the observation stream constructed by StreamManager and provides a stream of PatientMetric records.

## 2.5 Action Monitoring Module

This module running as Spark Streaming Job works on the PatientMetric stream which is the latest observations coming to PDS e.g. BG measurements, physical activity logs, dietary intake logs, medication intake logs, etc. The module matches these observations to scheduled actions for the day persisted in Patient State; the Action records and updates these records accordingly by the evaluation specifically performed for each action type to indicate how well patient adhere to planned action updating (actionTime, performance and actual attributes).

In addition to the updating the latest patient states, other components are notified with an event “PerformedActions” to continue the streaming. Figure 4 illustrates the stream processing flow starting from Kafka. In this example, stream window is 5 minutes which means Spark Streaming will give us 5 minutes’ data as micro batch. In other words, every 5 minutes we will get a collection of observations (RDD which is distributed collection of records) that is received within that 5-minute period (image we have millions of patients and we get thousands of observations for different patients every 5 minute).

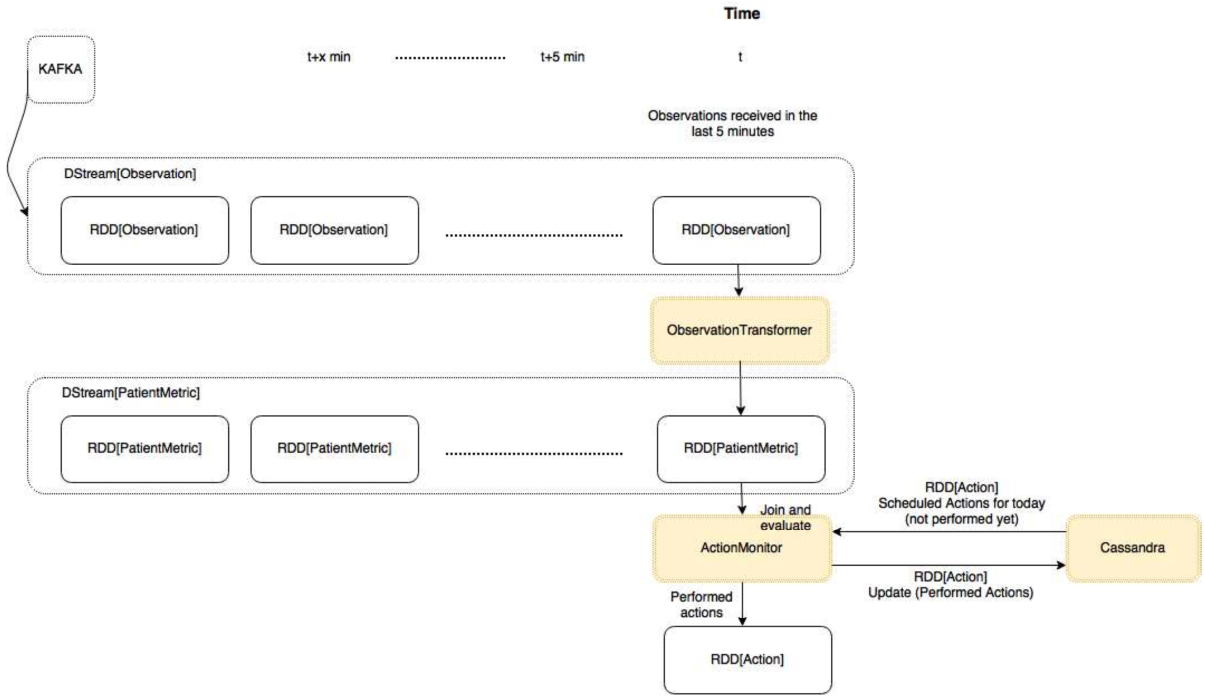



**Figure 4 Data flowing for ActionMonitor module**

ObservationTransformer runs for each micro batch (RDD) and transform the FHIR content into the PatientMetric record which is also given output as stream. ActionMonitor works on this stream and join the latest micro batch with the scheduled actions for that day which are not performed (matching observation to action; BG measurement to BG Monitoring action), and evaluate the performance point for each and update the Action records as performed.

## 2.6 Intervention Planning Modules

There are two planning modules for two different type of interventions; Reminders and After Event Motivations. Module for other intervention type; preventive interventions will be implemented for prototype 2.

### 2.6.1 Reminder Module

Reminder handling is implemented in two phases within Communication Engine. As user preferences for reminders are not expected to change frequently, we decided to make the reminder planning daily (at the end of day) for the next day.

Reminder module starts with the planned actions for the next day (Action records) then join them with the latest Intervention Preference records and produce a Reminder for the action if the patient prefers it for that action type by adjusting the timing according to the behaviour and scheduled time. e.g. BG monitoring schedules can be reminded 5 minutes before while walking session can be reminded 30 minutes before. By utilizing the Intervention Decision Handler, the intervention technique is decided (For prototype 1 it will be random among available ones). The resulting collection is persisted for the next day as scheduled reminders.

Then within the day, Reminder Module again periodically (every 5 minutes), runs a task that gets the scheduled Reminders in the upcoming 5 minutes, eliminate the invalid reminders (reminders that related action is already performed) and send them to Communication Delivery module for sending to patients.

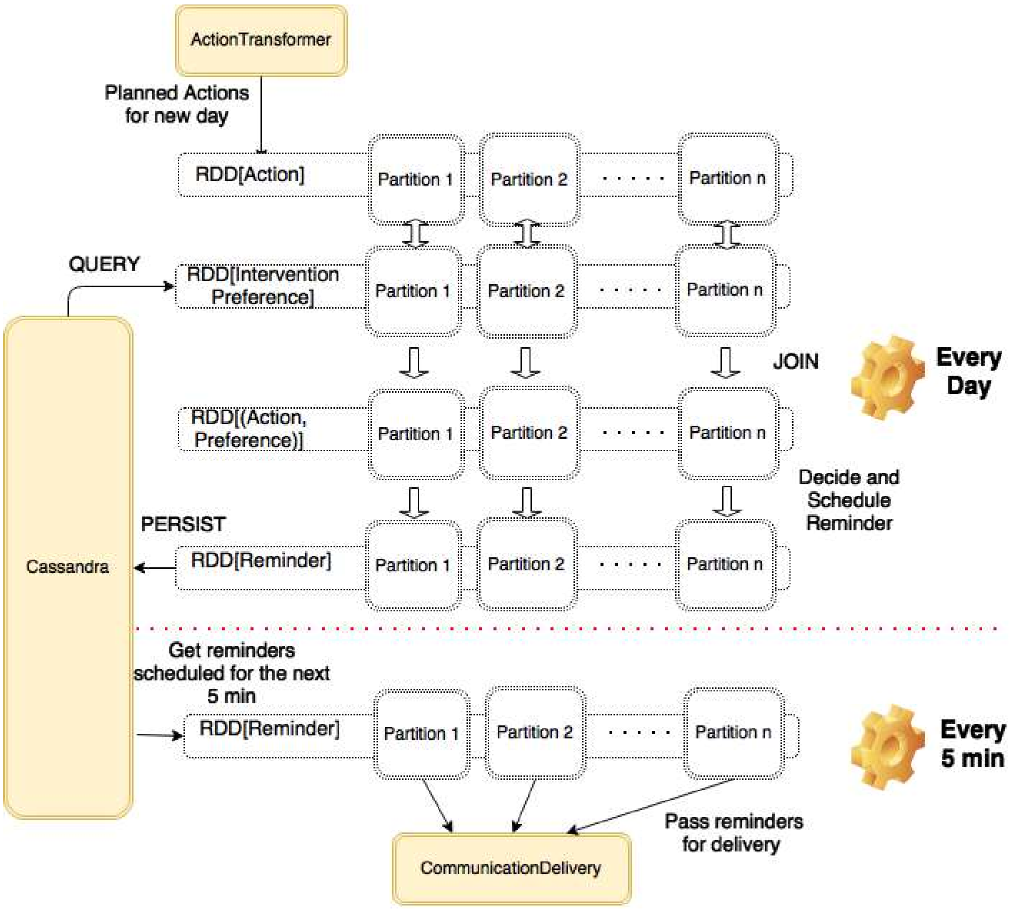



**Figure 5 Data flow with Reminder Scheduling**

Figure 5 illustrates how the process is managed within the Spark environment in a distributed way.

### 2.6.2 Motivation Module (Performed or Missed Actions)

Motivation Module runs two different evaluations one for performed actions and one for missed actions.

For missed actions, it periodically runs a task (every hour) to evaluate the missed actions in the past for that day and decide to give intervention for them or not. For this it retrieves the missed actions from the Cassandra, joins them with InterventionPreference records and latest AppliedIntervention records to form a patient state for each action type. InterventionDecisionHandler gets the joined patient state for each and decide on whether to give an intervention and the intervention technique to be used. Then for the resulting intervention techniques, if required, the MetricAnalytics module is to fill the content for the intervention. e.g. for social comparison with self we need some results to show to the patient → you walk %10 more than yesterday.

Similar evaluation is performed for performed actions, but this time the task runs continuously on the stream of performed actions coming from the ActionMonitor module.

### 2.6.3 Intervention Decision Handler

This module will provide the implementation of rules and algorithms to take the following decisions;

- Given patient state, decision to provide an intervention or not
- If the intervention will be provided, which intervention technique
- Timing of intervention

We will focus on these in the Prototype 2 and, for now, the implementation is simpler as described in Section 2.1. The decision for intervention is taken based on the patient preference and intervention technique is selected randomly among available ones. Timing is currently selected based on simple rules on action type and context.

The module is configured with available interventions where the model for each intervention definition is as follows;

**Intervention**

- **id -** Unique identifier of the intervention
- **category –** Category of the intervention (reminder, motivation in Prototype 2)
- **target –** The target behaviour (action code) that intervention is about
- **bct –** Main behavioural change technique intervention is using
- **context –** The context regarding how well patient is performing for his goal
- **contextTimeline –** The period that context is evaluated (instant, daily, weekly, monthly)
- **content –** The content of the intervention as template

e.g. The followings are the examples how we model some interventions

| | **Reminder for BG Monitoring** |
|---|---|
| **id** | … |
| **category** | reminder |
| **target** | bg-monitoring |
| **bct** | pcws (positive comparison with self) |
| **context** | goal-almost-achieved |
| **contextTimeline** | weekly |
| **content** | Almost there, you can still reach your weekly goal! You have a scheduled BG monitoring today after lunch. Keep on adhering your BG monitoring schedule this week and you will ${self-comparison}! Click to see details! |

| | **Motivation for BG monitoring** |
|---|---|
| **id** | … |
| **category** | motivation |
| **target** | bg-monitoring |
| **bct** | goal-review |
| **context** | goal-achieved |
| **contextTimeline** | daily |
| **content** | “Well done, you are doing an excellent job in BG monitoring. You reached your goal completely for the past 4 days. Click to see more details…” |

| | **Motivation for Walking** |
|---|---|
| **id** | … |
| **category** | motivation |
| **target** | walking-steps |
| **bct** | pcwo (Positive comparison with others) |
| **context** | goal-achieved |
| **contextTimeline** | daily |
| **content** | “Congratulations! Today you have walked %20 more than average person. Click to see more details…” |

| | Motivation for Nutrition (carb intake) |
|---|---|
| **id** | … |
| **category** | motivation |
| **target** | carb-intake |
| **bct** | reinforcement |
| **context** | goal-not-achieved |
| **contextTimeline** | daily |
| **content** | "Too bad you did not make it today for daily carb intake! But, you are doing well in general. Tomorrow might be a better day!" |

### 2.6.4 Performance Analytics

As described above, intervention decisions are based on context about patient state regarding a specific goal (or behaviour in other words). Therefore, we need this information ready within the patient state. These goal contexts (achieving a goal, almost achieving a goal, etc.) can be evaluated in different temporal periods; daily, weekly, monthly, etc.

One of the responsibilities of Performance Analytics module is to calculate these periodic goal performance evaluations (ensure that they are up to date) and persist them in Cassandra as GoalPerformance records. At the end of each day the following goal context records are calculated and stored for each active goal of patient;

- Last day performance for each active goal of each patient
- Current week performance for each active goal of each patient (week→ Monday to Sunday)
- Current biweekly performance for each active goal of each patient
- Current month performance for each active goal of each patient
- Current 3-month performance for each active goal of each patient

As we calculate daily performances for each day, calculation of others are easy tasks just some type of averaging of the days in the period.
For the second prototype, Performance Analytics will also run batch analytic jobs on PatientMetric records to calculate a range of statistics (avg, median, etc.) for the metrics and persist them again as PatientMetric.

Another functionality of Performance Analytics module is to provide a service to Motivation and Reminder Modules to find;

- A list of "Positive comparisons with self" cases for the given goal and patient
    - e.g. For walking-steps, today is your best day in the last week, today %10 more than yesterday, this week %15 more than your average, today %20 more than your worst daily performance
- A list of "Positive comparison with others" cases for the given goal and patient
    - e.g. For carb-intake, today %10 less than others with the carb goal, etc.
- A goal review patterns for the given goal and patient
    - e.g. Your performance is increasing steadily this week!

### 2.6.5 Communication Delivery

This module is simply a push notification client and use Google's Firebase libraries to send the push notification with the given intervention content.

Notification parameters are as follows;

- **body:** The message itself showing the intervention's main message for the patient (e.g. Keep running, you have completed half of your exercise plan!)
- **title:** The title of the message
- **icon:** The icon to show with the message

The (data) payload parameters are as follows;

- **intervention:**
    - **id:** The identifier of the intervention instance
    - **interventionId:** Unique identifier for intervention
    - **target:** Target behaviour or issue for the intervention
    - **interventionType:** The identifier indicating the bct technique for intervention
    - **params:** The parameter list for the intervention (key, value pairs).

# 3 Functionality Demonstrations

It is difficult to demonstrate the functionality of Communication Engine as it is designed to work continuously and time is an important aspect in all decisions regarding the intervention delivery. Therefore, here we illustrate how system work for each phase by describing the previous state and latest state for each task.

For the example, we focus on BG monitoring as the goal(behaviour) that will be monitored and interventions will be delivered about.

### 3.1.1 Preparing Patient state for a day (Daily transformations of resources)

We create data for 3 patients for this demonstration with resources; Goal, ActionPlan, UserSetting and CommunicationPreference within PDS. The following tables show the summary of data.

| | **Patient Identifier** | **BGM Monitoring Adherence Goal (for next 3 months)** |
|---|---|---|
| **Patient 1** | 9d46a3a4-e0e8-4778-b2de-0765966e0cff | 85% |
| **Patient 2** | e77446e0-a1eb-4691-8709-20fc12b62b8b | 85% |
| **Patient 3** | 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | 90% |

| | **BGM Action Plan** | **Period scheduled for (starting 2017-04-09)** |
|---|---|---|
| **Patient 1** | Every day 3 times; 1 hour after breakfast, lunch and dinner | 3 days |
| **Patient 2** | Every week-days 2 times; at 10:00 and 16:00 | 3 days |
| **Patient 3** | Every day 2 times | 2 days |

| | **User Settings** |
|---|---|
| **Patient 1** | wakeup_time_weekday → 08:30<br>breakfast_time_weekday → 09:00<br>lunch_time_weekday → 13:00<br>dinner_time_weekday → 18:30<br>sleeping_time_weekday →24:00<br>wakeup_time_weekend → 11:00<br>breakfast_time_weekend → 11:30<br>lunch_time_weekend → 15:00<br>dinner_time_weekend → 19:00<br>sleeping_time_weekend →24:00 |

| | **CommunicationPreference** |
|---|---|
| **Patient 1** | Reminder →MANDATORY<br>Motivation → PREFERRED |
| **Patient 2** | Reminder →NEVER<br>Motivation → MANDATORY |
| **Patient 3** | Reminder →MANDATORY |

| | |
|---|---|
| | Motivation → ACCEPTABLE |

**Error! Reference source not found.** shows the query response from PDS which list all ActionPlan resources after creating the above resources.

Figure 6 illustrates the Cassandra tables (patient state), after running the transformation for the first day (2017-04-09). As you can see the power2dm.active_goals tables contain 3 entries corresponding to the information given above. Similarly, power2dm.intervention_preferences have the 6 entries corresponding to preferences of each patient for “Reminders” and “Motivations” for BG monitoring behaviour.

The “power2dm.action_performance” table, on the other hand, only have scheduled actions for Patient 1 and Patient 3. The reason is that the action plan for Patient 2 is only scheduled for weekdays and the 2017-04-09 is Sunday.

For Patient 1, we have 3 scheduled actions for the day;

- 20:00 which is 1 hour after patient’s dinner time at weekends; 19:00 (see UserSettings of Patient 1)
- 16:00 which is 1 hour after patient’s lunch time at weekends; 15:00 (see UserSettings of Patient 1)
- 12:30 which is 1 hour after patient’s brekfast time at weekends; 11:30 (see UserSettings of Patient 1)

For Patient 3, as timings are not indicated, two Action records for the one day period are created. As we run the system in +3 timezone, it taks the day period from 21:00 for 21:00 next day.

```
cqlsh:power2dm> select * from power2dm.action_performance;

 pid                                  | action      | scheduled_time                  | action_order | action_time | actual | expected | performance | scheduled_until                 | total_action
--------------------------------------+-------------+---------------------------------+--------------+-------------+--------+----------+-------------+---------------------------------+--------------
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 20:00:00.000000+0000 |            3 |        null |   null |     null |        null |                            null |            3
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 16:00:00.000000+0000 |            2 |        null |   null |     null |        null |                            null |            3
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 12:30:00.000000+0000 |            1 |        null |   null |     null |        null |                            null |            3
 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-09 00:00:00.000000+0000 |            1 |        null |   null |     null |        null | 2017-04-09 21:00:00.000000+0000 |            2
 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-09 00:00:00.000000+0000 |            2 |        null |   null |     null |        null | 2017-04-09 21:00:00.000000+0000 |            2

(5 rows)
cqlsh:power2dm> select * from power2dm.active_goals;

 pid                                  | goal      | expected | valid_from                      | valid_until
--------------------------------------+-----------+----------+---------------------------------+---------------------------------
 e77446e0-a1eb-4691-8709-20fc12b62b8b | 308113006 |     85.0 | 2017-04-08 21:00:00.000000+0000 | 2017-07-08 21:00:00.000000+0000
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | 308113006 |     85.0 | 2017-04-08 21:00:00.000000+0000 | 2017-07-08 21:00:00.000000+0000
 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | 308113006 |     90.0 | 2017-04-08 21:00:00.000000+0000 | 2017-07-08 21:00:00.000000+0000

(3 rows)
cqlsh:power2dm> select * from power2dm.intervention_preferences;

 pid                                  | behaviour   | intervention_type | preference
--------------------------------------+-------------+-------------------+------------
 e77446e0-a1eb-4691-8709-20fc12b62b8b | monitor_bgm |        motivation |          5
 e77446e0-a1eb-4691-8709-20fc12b62b8b | monitor_bgm |          reminder |          0
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm |        motivation |          4
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm |          reminder |          5
 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm |        motivation |          2
 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm |          reminder |          5

(6 rows)
```

**Figure 6 Cassandra tables after transformation - 1st day**

```
cqlsh:power2dm> select * from power2dm.action_performance;

 pid                                  | action      | scheduled_time                  | action_order | action_time | actual | expected | performance | scheduled_until                 | total_action
--------------------------------------+-------------+---------------------------------+--------------+-------------+--------+----------+-------------+---------------------------------+--------------
 e77446e0-a1eb-4691-8709-20fc12b62b8b | monitor_bgm | 2017-04-10 16:00:00.000000+0000 |            2 |        null |   null |     null |        null |                            null |            2
 e77446e0-a1eb-4691-8709-20fc12b62b8b | monitor_bgm | 2017-04-10 10:00:00.000000+0000 |            1 |        null |   null |     null |        null |                            null |            2
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-10 19:30:00.000000+0000 |            3 |        null |   null |     null |        null |                            null |            3
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-10 14:00:00.000000+0000 |            2 |        null |   null |     null |        null |                            null |            3
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-10 10:00:00.000000+0000 |            1 |        null |   null |     null |        null |                            null |            3
 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-09 21:00:00.000000+0000 |            1 |        null |   null |     null |        null | 2017-04-10 21:00:00.000000+0000 |            2
 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-09 21:00:00.000000+0000 |            2 |        null |   null |     null |        null | 2017-04-10 21:00:00.000000+0000 |            2

(7 rows)
```

**Figure 7 ActionPerformance table for 2nd day**

```
cqlsh:power2dm> select * from power2dm.action_performance;

 pid                                  | action      | scheduled_time                  | action_order | action_time | actual | expected | performance | scheduled_until                 | total_action
--------------------------------------+-------------+---------------------------------+--------------+-------------+--------+----------+-------------+---------------------------------+--------------
 e77446e0-a1eb-4691-8709-20fc12b62b8b | monitor_bgm | 2017-04-11 16:00:00.000000+0000 |            2 |        null |   null |     null |        null |                            null |            2
 e77446e0-a1eb-4691-8709-20fc12b62b8b | monitor_bgm | 2017-04-11 10:00:00.000000+0000 |            1 |        null |   null |     null |        null |                            null |            2
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-11 19:30:00.000000+0000 |            3 |        null |   null |     null |        null |                            null |            3
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-11 14:00:00.000000+0000 |            2 |        null |   null |     null |        null |                            null |            3
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-11 10:00:00.000000+0000 |            1 |        null |   null |     null |        null |                            null |            3
 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-10 21:00:00.000000+0000 |            1 |        null |   null |     null |        null | 2017-04-10 23:59:59.000000+0000 |            2
 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-10 21:00:00.000000+0000 |            2 |        null |   null |     null |        null | 2017-04-10 23:59:59.000000+0000 |            2

(7 rows)
```

**Figure 8 ActionPerformance table for 3rd day**

```
cqlsh:power2dm> select * from power2dm.action_performance;

 pid | action | scheduled_time | action_order | action_time | actual | expected | performance | scheduled_until | total_action
-----+--------+----------------+--------------+-------------+--------+----------+-------------+-----------------+--------------

(0 rows)
```

**Figure 9  ActionPerformance table for 4th day**

When we run the transformers the next day, other tables will be same as they get the latest active records. For Actions, as you can see from the Figure 7, this time we have records for all patients as the 2.day is a weekday. For Patient 2, we have two records with the given times. For Patient 1, the timings are changed as his weekday preferences are different.

Figure 8 shows the results after running the transformation for the 3rd day. Only change this time is for Patient 3, for which the period of the scheduled actions is narrower. Normally, there would be no record if we run the system configured for TimeZone Z. Figure 9 illustrates this as the planned actions are valid only for the first 3 days for Patient 1 and Patient 2 and 2 days for Patient 3.

### 3.1.2 Reminder Planning for the next day

As described above, in this prototype, we decided to make the reminders planning daily for the next day. Action transformation when finished trigger an event PlannedActionsForNextDay with the including the collection of planned actions. The ReminderHandler is listening these events and start the procedure of reminder planning when it receives the event.

```
cqlsh:power2dm> select * from power2dm.reminders;

 pid                                  | action      | planned                         | action_order | until
--------------------------------------+-------------+---------------------------------+--------------+---------------------------------
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 19:40:00.000000+0000 |            3 | 2017-04-09 19:50:00.000000+0000
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 15:40:00.000000+0000 |            2 | 2017-04-09 15:50:00.000000+0000
 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 12:10:00.000000+0000 |            1 | 2017-04-09 12:20:00.000000+0000
 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-09 18:00:00.000000+0000 |            2 | 2017-04-09 18:20:00.000000+0000
 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-09 13:00:00.000000+0000 |            1 | 2017-04-09 13:20:00.000000+0000

(5 rows)
```

**Figure 10 Scheduled reminders for the 1st day**

Assume that we are on the first day, the system runs the tasks for the beginning of the day to prepare the Patient state and reminders for the next day. Figure 10 shows the resulting reminders in the persistency after running the tasks.

Patient 1 (id: 9d46…) has preference for reminders so the system schedule a reminder for each planned action for the next day, just before 20 minutes (configurable value) from the action.

Patient 2 has no reminder because he selects "Never" for reminders.

Patient 3 (id: 798…) has 2 reminders as he selects "Mandatory" for reminder preference. However, this time as he doesn't have specific times for the actions, the reminders are scheduled throughout the day according to their numbers.

### 3.1.3 Continuous Action Monitoring within the day

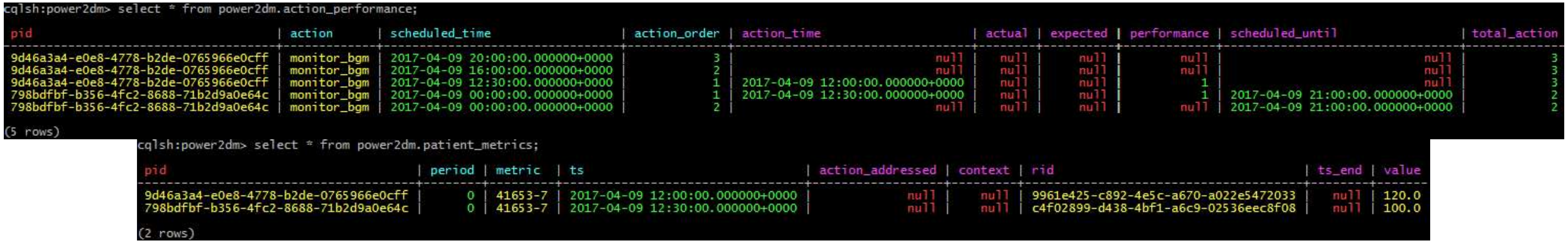
Now assume that we are on the 1st day, patient state is ready, and the patients measures their BG. We assume that Patient 1 make the following BG measurements;

- At 12:00, 120 mg/dl
- At 20:30, 130 mg/dl

And Patient 3 make the following BG measurements;

- At 12:30, 110 mg/dl
- At 17:00, 100 mg/dl

We run the action monitoring system for every hour (streaming window will be chosen for more narrow periods like 1 min) to illustrate the functionality. The Figure 11, Figure 12, and Figure 13 illustrates the state of "action_performance" and "patient_metrics" table within some periods.



cqlsh:power2dm> select * from power2dm.action_performance;

| pid | action | scheduled_time | action_order | action_time | actual | expected | performance | scheduled_until | total_action |
|---|---|---|---|---|---|---|---|---|---|
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 20:00:00.000000+0000 | 3 | null | null | null | null | null | 3 |
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 16:00:00.000000+0000 | 2 | null | null | null | null | null | 3 |
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 12:30:00.000000+0000 | 1 | 2017-04-09 12:00:00.000000+0000 | null | null | 1 | null | 3 |
| 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-09 00:00:00.000000+0000 | 1 | 2017-04-09 12:30:00.000000+0000 | null | null | 1 | 2017-04-09 21:00:00.000000+0000 | 2 |
| 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-09 00:00:00.000000+0000 | 2 | null | null | null | null | 2017-04-09 21:00:00.000000+0000 | 2 |

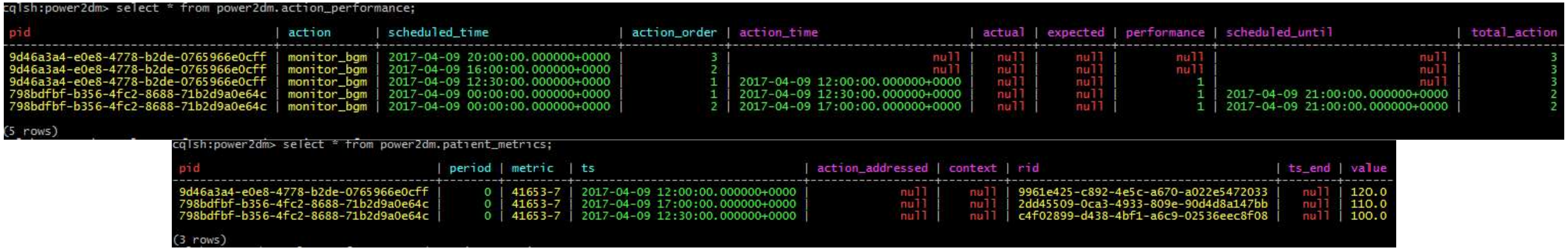
(5 rows)

cqlsh:power2dm> select * from power2dm.patient_metrics;

| pid | period | metric | ts | action_addressed | context | rid | ts_end | value |
|---|---|---|---|---|---|---|---|---|
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | 0 | 41653-7 | 2017-04-09 12:00:00.000000+0000 | null | null | 9961e425-c892-4e5c-a670-a022e5472033 | null | 120.0 |
| 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | 0 | 41653-7 | 2017-04-09 12:30:00.000000+0000 | null | null | c4f02899-d438-4bf1-a6c9-02536eec8f08 | null | 100.0 |

(2 rows)

**Figure 11 Action matchings with observations for 12:00 – 13:00**



cqlsh:power2dm> select * from power2dm.action_performance;

| pid | action | scheduled_time | action_order | action_time | actual | expected | performance | scheduled_until | total_action |
|---|---|---|---|---|---|---|---|---|---|
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 20:00:00.000000+0000 | 3 | null | null | null | null | null | 3 |
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 16:00:00.000000+0000 | 2 | null | null | null | null | null | 3 |
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 12:30:00.000000+0000 | 1 | 2017-04-09 12:00:00.000000+0000 | null | null | 1 | null | 3 |
| 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-09 00:00:00.000000+0000 | 1 | 2017-04-09 12:30:00.000000+0000 | null | null | 1 | 2017-04-09 21:00:00.000000+0000 | 2 |
| 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-09 00:00:00.000000+0000 | 2 | 2017-04-09 17:00:00.000000+0000 | null | null | 1 | 2017-04-09 21:00:00.000000+0000 | 2 |

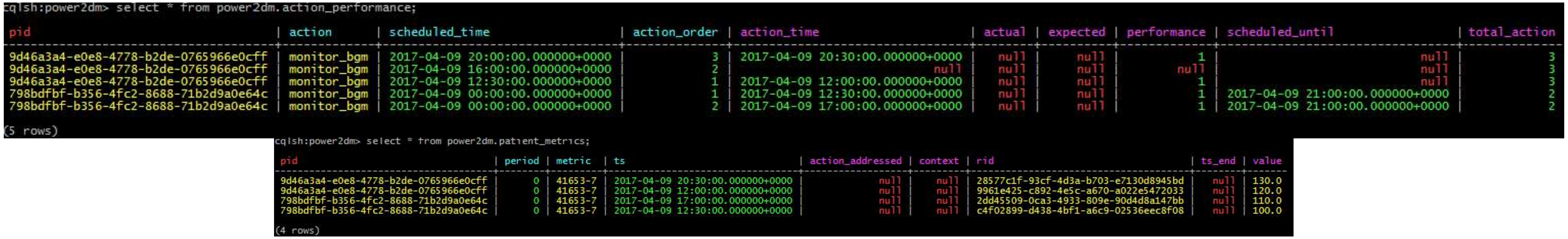
(5 rows)

cqlsh:power2dm> select * from power2dm.patient_metrics;

| pid | period | metric | ts | action_addressed | context | rid | ts_end | value |
|---|---|---|---|---|---|---|---|---|
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | 0 | 41653-7 | 2017-04-09 12:00:00.000000+0000 | null | null | 9961e425-c892-4e5c-a670-a022e5472033 | null | 120.0 |
| 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | 0 | 41653-7 | 2017-04-09 17:00:00.000000+0000 | null | null | 2dd45509-0ca3-4933-809e-90d4d8a147bb | null | 110.0 |
| 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | 0 | 41653-7 | 2017-04-09 12:30:00.000000+0000 | null | null | c4f02899-d438-4bf1-a6c9-02536eec8f08 | null | 100.0 |

(3 rows)

**Figure 12 Action matchings with observations for 17:00 – 18:00**



cqlsh:power2dm> select * from power2dm.action_performance;

| pid | action | scheduled_time | action_order | action_time | actual | expected | performance | scheduled_until | total_action |
|---|---|---|---|---|---|---|---|---|---|
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 20:00:00.000000+0000 | 3 | 2017-04-09 20:30:00.000000+0000 | null | null | 1 | null | 3 |
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 16:00:00.000000+0000 | 2 | null | null | null | null | null | 3 |
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | 2017-04-09 12:30:00.000000+0000 | 1 | 2017-04-09 12:00:00.000000+0000 | null | null | 1 | null | 3 |
| 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-09 00:00:00.000000+0000 | 1 | 2017-04-09 12:30:00.000000+0000 | null | null | 1 | 2017-04-09 21:00:00.000000+0000 | 2 |
| 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | 2017-04-09 00:00:00.000000+0000 | 2 | 2017-04-09 17:00:00.000000+0000 | null | null | 1 | 2017-04-09 21:00:00.000000+0000 | 2 |

(5 rows)

cqlsh:power2dm> select * from power2dm.patient_metrics;

| pid | period | metric | ts | action_addressed | context | rid | ts_end | value |
|---|---|---|---|---|---|---|---|---|
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | 0 | 41653-7 | 2017-04-09 20:30:00.000000+0000 | null | null | 28577c1f-93cf-4d3a-b703-e7130d8945bd | null | 130.0 |
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | 0 | 41653-7 | 2017-04-09 12:00:00.000000+0000 | null | null | 9961e425-c892-4e5c-a670-a022e5472033 | null | 120.0 |
| 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | 0 | 41653-7 | 2017-04-09 17:00:00.000000+0000 | null | null | 2dd45509-0ca3-4933-809e-90d4d8a147bb | null | 110.0 |
| 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | 0 | 41653-7 | 2017-04-09 12:30:00.000000+0000 | null | null | c4f02899-d438-4bf1-a6c9-02536eec8f08 | null | 100.0 |

(4 rows)

**Figure 13 Action matchings with observations for 20:00 – 21:00**

After the processing of observations between 12:00-13:00, we have corresponding records in the patient metrics table one for Patient 1's measurement and one for Patient 3's measurement. Also, they are matched with the closest scheduled actions for those patients;

- Patient 1's measurement at 12:00 with his action planned for 12:30
- Patient 3's measurement at 12:30 with his first action planned within the day (action order 1)

As you can see the "performance" is set to 1 for each. Then between 17:00-18:00 another entry is created in the tables. Patient 3's measurement match with the second planned action. Then the last entry comes between 20:00-21:00 from Patient 1's measurement. It matches with the last planned action scheduled for 20:00 and the second scheduled is missed as you can see.

### 3.1.4 Evaluation of performance for the past day

At the beginning of the next day (2.day), the system runs the Performance Analytics module and calculate the behavioural performance for the last day. Figure 14 shows the results, as you can see Patient 1 has 66% adherence as he missed one action and Patient 3 has full adherence 100%.

Then the system runs the evaluation service to calculate latest behaviour states for patients. Figure 15 illustrates the states after the calculations. As you can see for Patient 1; all recent performance, last day performance and last week performance are set to 0.67 as there is no performance record previously. The same applies to Patient 2 which completely achieved the daily goal for the previous day.

### 3.1.5 Intervention planning and delivery

Now, assume that in the second day our Patient 1 has performed the following BG measurements which are all complaint with what is planned for the patient;

- At 10:12, 150 mg/dl (planned to 10:00)
- At 14:20, 170 mg/dl (planned to 14:00)
- At 19:27, 125 mg/dl (planned to 19:30)

We run the MotivationHandler every 3 hour, starting from 8; to evaluate the last 3 hours for missed and performed actions (Normally it will be a narrower); 8-11, 11-14, 14-17 and 17-20 ...

Figure 16 illustrates the applied interventions table state when the evaluation is done between 8:00 to 11:00. As Patient 2, does not measure his BG although he has a planned one at 10:00 and he has the preference MANDATORY for the motivations, the system delivers an "general-reinforcement" intervention; "You have missed your BG monitoring ….".

For Patient 1, as his preference is PREFERED, the delivery of intervention is delayed to later actions (PREFERED means at least one intervention per day and choice of time within day is random). But later during the evaluation between 14:00 to 17:00, Patient 1 has received a "comparison-with-self" intervention. As he measures his BG both at 10:12 and 14:20 as planned, he is almost achieving his goal so system decides to motivate him and find a positive comparison from the past data; BehaviourState (will be 33% better his recent performance).

As Patient 2 has preference MANDATORY, he again gets an intervention regarding the second planned action. As it is the last action, the intervention is about the today's overall performance. In this deliverable, we cannot show the delivery of these intervention through Mobile Application as they are not integrated yet.

cqlsh:power2dm> select * from power2dm.goal_performances;

| pid | period | goal | period_start | evaluations | expected | performance | period_end |
|---|---|---|---|---|---|---|---|
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | 1 | monitor_bgm | 2017-04-08 21:00:00.000000+0000 | null | 85.0 | 0.666667 | 2017-04-09 21:00:00.000000+0000 |
| 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | 1 | monitor_bgm | 2017-04-08 21:00:00.000000+0000 | null | 90.0 | 1 | 2017-04-09 21:00:00.000000+0000 |

(2 rows)

**Figure 14 Goal Performance table after 1st day**

cqlsh:power2dm> select * from power2dm.behaviour_states;

| pid | behaviour | performance |
|---|---|---|
| e77446e0-a1eb-4691-8709-20fc12b62b8b | monitor_bgm | null |
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | {'ldp': 0.666667, 'lwp': 0.666667, 'rp': 0.666667} |
| 798bdfbf-b356-4fc2-8688-71b2d9a0e64c | monitor_bgm | {'ldp': 1, 'lwp': 1, 'rp': 1} |

(3 rows)

**Figure 15 Behaviour States after 1st day**

cqlsh:power2dm> select * from power2dm.applied_interventions;

| pid | behaviour | intervention_type | ts | bct | content |
|---|---|---|---|---|---|
| e77446e0-a1eb-4691-8709-20fc12b62b8b | monitor_bgm | motivation | 2017-04-10 11:00:00.000000+0000 | general-reinforcement | You have missed your BG monitoring. But you can still pursue your goal by complying with the remaining 1 schedules! |

(1 rows)

**Figure 16 Applied interventions (8:00-11:00)**

cqlsh:power2dm> select * from power2dm.applied_interventions;

| pid | behaviour | intervention_type | ts | bct | content |
|---|---|---|---|---|---|
| e77446e0-a1eb-4691-8709-20fc12b62b8b | monitor_bgm | motivation | 2017-04-10 17:00:00.000000+0000 | general-reinforcement | This was not your best day in BG monitoring! It is OK, you will be better tomorrow! |
| e77446e0-a1eb-4691-8709-20fc12b62b8b | monitor_bgm | motivation | 2017-04-10 11:00:00.000000+0000 | general-reinforcement | You have missed your BG monitoring. But you can still pursue your goal by complying with the remaining 1 schedules! |
| 9d46a3a4-e0e8-4778-b2de-0765966e0cff | monitor_bgm | motivation | 2017-04-10 17:00:00.000000+0000 | comparison-with-self | Almost there in your BG monitoring goal! Keep on going and you will be 33% better than your recent performance in BG monitoring. |

(3 rows)

**Figure 17 Applied Interventions (14:00-17:00)**