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 D3.4 (or D3.2.1b)

Recommender Engine

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1 Introduction

1.1 Purpose and Scope

The purpose of deliverable D3.4 is to provide the improvements and changes in the software architecture and implementation of Communication Engine since Prototype I (as described in D3.3 Recommender Engine I) and deliver its latest demonstration. This document only describes the major changes and improvements in the implementation.

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 I
- D4.1 Personal Data Model and Service API
- D3.2 Dynamic Health Behaviour Change Intervention Models for Self-management II
- D3.3 Recommender Engine I

2 Changes and Improvements in the Architecture

2.1 Approach for Intervention Delivery

In comparison to Prototype I and what is described in D3.3, there are some slight changes in the approach for intervention delivery;

One of them is related with Patient's preferences on interventions. Based on discussions with behaviour change experts, the following is the final preferences and how they are evaluated;

- **Each Time (Always):** For each planned action 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 70% of the time among the times an action is planned.
- **Occasionally:** The intervention will be delivered 30% of the time among the times an action is planned.
- **Rarely:** The intervention will be delivered 10% of the time among the times an action is planned.
- **Never:** The intervention will never be sent.

Another change regarding categorization of interventions is that, preventive interventions are decided to be excluded as in general terms consortium does not want POWER2DM to be evaluated as a medical application.

As described in D3.2, only the following BCTs are included in Communication Engine;

- Positive comparison with self
- Positive comparison with others
- General reinforcement
- Planning and goal setting
- Giving feedback about goals

Context categorization is updated as follows;

- **UNKNOWN (-1)**: Not enough data to evaluate e.g. day is not finished yet so daily goal context is unknown
- **ACHIEVED LESS THAN GOAL (0)**
- **ALMOST ACHIEVED GOAL (1)**
- **ABOUT TO ACHIEVE GOAL (2):** Patient has very few remaining actions (or remaining time in a period) and is close to achieve his goal
- **ACHIEVED GOAL (3)**
- **ACHIEVED MORE THAN GOAL (4)**

Regarding selection of intervention type and timing, we have implemented a more complex approach using Reinforcement Learning. However it is not integrated to latest Communication Engine Prototype based on the decision of behaviour change experts who wants to try out the basic approach in the Evaluation Campaign. The publication "An Expandable Approach for Design and Personalization of Digital, Just-In-Time Adaptive Interventions" which is accepted by the Journal of the American Medical Informatics Association (JAMIA) describes this approach in detail. As a result, approach for the current prototypes is still as follows;

- Randomly select the intervention technique among the available ones for the specific goal
- 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!'"

2.2 Architecture and Technologies Used

The architecture of Communication Engine is updated as shown in Figure 1. Major difference from initial version (D3.3) is removing the batch layer and implementing the intervention planning as complete Stateful Stream Processing architecture where patient state is maintained in memory storage provided by Spark. So as a result, new approach does not need a database, so we removed the Cassandra from the stack. In this way, we also unify the intervention planning for reminders and motivations where the behaviour and BCT specific functionality is implemented as modules that can be integrated to the core system.

In this new architecture, CommunicatioEngine keeps a state, contextual information that is needed to decide and plan intervention delivery, for each patient by using Spark Stateful Processing architecture. These patient states are first initialized when CommunicationEngine is started with past data already accumulated at PDS (by configurations we can specify the time limit) and then the state is continuously updated by the streaming data coming from PDS after this time through Kafka. Then by getting a stream of patient states from PatientStateManager, InterventionPlanner evaluate the patient state for each interval and plan the interventions.

The followings are the summary of functionalities for each sub-module;

- **FHIR Rest View:** Component that calls the PDS FHIR Rest API to retrieve data in FHIR resource format. Used only for initialization of patient states when starting the CommunicationEngine component to retrieve accumulated data in PDS.
- **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.

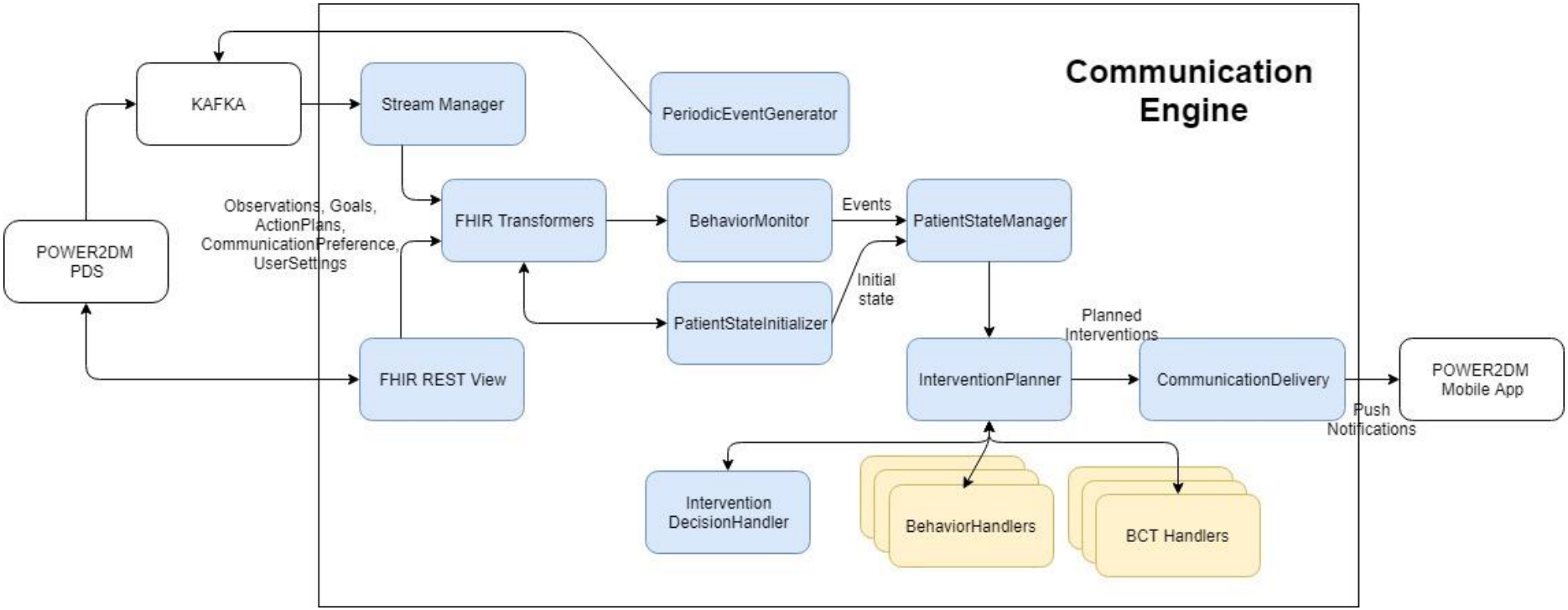

Figure 1 Internal Architecture of Communication Engine

- **PatientStateManager:** Keeps the state for each patient and updates it based on the incoming event stream coming from the BehaviorMonitor.
- **PatientStateInitializer:** Coordinate the initialization of patient states based on the retrieved data from PDS.
- **InterventionPlanner:** It runs on the stream of patient states, and run the intervention planning algorithm for each patient state continuously. It outputs the planned interventions as a stream to CommunicationDelivery component.
- **InterventionDecisionHandler:** Module used by InterventionPlanner to decide on the intervention type (e.g. positive comparison with self vs social support) and timing of intervention.
- **Behavior Handlers:** These are pluggable modules specific to each defined behaviour to handle behaviour specific performance calculations from the patient state.
- **BCT Handler:** These are pluggable modules specific to each BCT supported to handle the customization of intervention content; specifically calculations of the values of placeholders used in intervention definition.
- **CommunicationDelivery:** Retrieve the intervention schedules and perform the deliveries by sending the push notifications.
- **PeriodicEventGenerator:** Generates end of day events in Kafka at the end of days, which causes the PatientStateManager to updates the patient states at the end of each day for daily, weekly, and monthly performance calculations.

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 Events

Figure 2 illustrates the latest data model for Patient State which is maintained and updated continuously for each patient by CommunicationEngine.

PatientState is the main entity that represents the state for a specific patient.

- pid: Patient identifier (pseudonym identifier from PDS)
- lastUpdateTime: Latest time that patient state is updated
- dailyEvents: Time of important daily events which can be used for relative action schedulings (e.g. wake up time, breakfast time, etc). This information is obtained from related Observation event stream.
- context: All contextual data about patient accumulated until now
- behaviorStates: BehaviorState entities that represent the state for each monitored behaviour for the patient
- patientSettings: General settings for the patient
- interventionPreferences: Prefernces of patient for each behaviour and intervention category

PatientSettings represents the general settings for patient.

- language → Patient's preferred language
- timezone → Patinet's time zone
- weekendEventTimings -> General time preferences of patient for weekend related with specific daily events (breakfast, wake up, lunch, etc)
- weekdayEventTimings -> General time preferences of patient for weekdays related with specific daily events

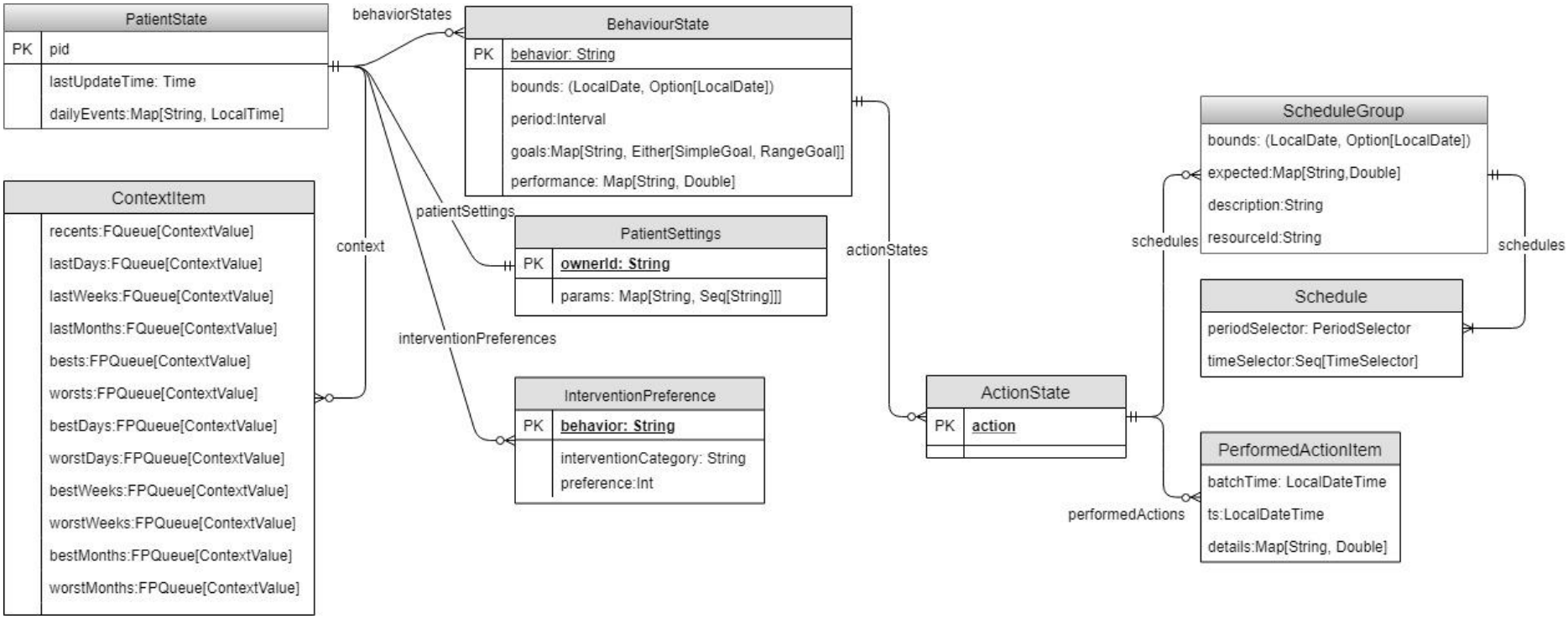

Figure 2 Patient State Model

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)

BehaviorState is entity that represents the state for a specific monitored behaviour (e.g. state of Blood Glucose Monitoring behaviour). A behaviour state is only created for a behaviour if a related Self-Management Goal is set for this patient.

- behaviour: Id of the behaviour
- bounds: Indicates the period that this behaviour should be monitored between
- period: Current period that this behavior is evaluated for (e.g. for daily evaluated behaviors like Blood Glucose Monitoring this is the current day)
- goals: Provides the numerical goals related with this behaviour
- goalResourceId: Identifier of the FHIR Goal resource that this behaviour monitoring is about
- actionStates: State for different planned actions for the behaviour.

ActionState is the entity that represents the state for a planned action for the behaviour (e.g. state for Walking schedules under Exercise behavior).

- action: Identifier of the action
- schedules: Provides the scheduling information for the planned action
- performedActions: Related performed actions by patient within the period of behaviour (BehaviorState.period)

SceduleGroup is the entity representing scheduling information for a POWER2DM Action Plan for a behaviour.

- bounds: Date interval that this scheduling (planned action) is valid
- expected: Numerical expected requirements related with the action (e.g. duration for walking)
- description: Description of planned action
- resourceId: Identifier of corresponding POWER2DM Action Plan resource in PDS
- schedules: All schedules

Schedule is the entity representing a single scheduled time for a planned action (e.g. Blood Glucose Monitoring before breakfast, Waking on Wednesdays at 21:00)

- periodSelector: Schedule period; a specific date (e.g. 2018-10-11), specific day of weeks (e.g. Wednesday and Saturday), daily, weekly, monthly
- timeSelector: List of scheduled times with the period; a specific local time (e.g. 10:30), a relative time (e.g. 10 minutes before breakfast), or any time within day

PerformedActionItem is the entity representing an action performed by patient.

- ts: Time that this action is performed
- details: Details of the performed action (e.g. duration of a walk)

ContextItem is the entity representing state information about a specific patient context. This can be about a behavioural performance e.g. Self Blood Glucose Monitoring Performance, Exercise Performance or another health status context e.g. patient stress or mood.

- recents: Recent values for this context
- lastDays: Values of the context in the last days
- lastWeeks: Values of the context in the last weeks
- lastMonths: Values of the context in the last months
- bests: Best values of the context ever
- worsts: Worst values of the context ever

- bestDays: Best daily values of the context ever
- worstDays: Worst daily values of the context ever
- bestWeeks: Best weekly values of the context ever
- worstWeeks: Worst weekly values of the context ever
- bestMonths: Best monthly values of the context ever
- worstMonths: Worst monthly values of the context ever

As shown in the definition of ContextItem, each value is represented by a abstract ContextValue entity. For each behaviour, an implementation of this abstract class is provided which holds the performance of patient for that behaviour. For example, SMBGPerformance represents the patient's Self Blood Glucose Monitoring performance by specific parameters like number of blood glucose measurement expected, number of matched (as planned) blood glucose measurement performed, number of unmatched (unplanned) blood glucose measurements in addition to common parameters like time for this evaluation (timestamp for instant actions, day for daily evaluations, week for weekly evaluations, month for monthly evaluations) and total number of values averaged to find this value. Also FiniteQueue and FinitePriorityQueue data structures are used to hold values for each periodic evaluation and number of values to hold in these queues can be configured for each behaviour. e.g. performance of SMBG monitoring can be hold for last 15 days, last 8 weeks, last 6 months, 3 best days, 3 best weeks, etc.

Each patient state is updated based on the event stream coming from BehaviorMonitor. These event types are as follows;

- **BehavioralGoal** is the event which indicates a behavioural goal set or unset for a patient. (Adhere your blood glucose measurement tasks, and monitor this behaviour)
- **PlannedAction** is the event which indicates an action plan created or revoked for a behaviour for a patient. (e.g. Blood Glucose Measurement should be done before each meal)
- **PerformedAction** is the event which indicates an action is performed related with a behaviour by patient (e.g. patient performs Blood Glucose Measurement at 10:00)
- **PatientObservation** is the event which indicates an observation is received for a patient (e.g. blood glucose measurement of 130 mg/dl is received at 10:00)
- **SettingsChanged** is the event indicating a change in patient settings
- **InterventionPreferencesChanged** is the event indicating a change in intervention preferences
- **EndOfDay** is the event indicating the end of day for each day

2.4 Transforming FHIR resources to Internal Model

We have a transformer that process the corresponding POWER2DM resource(s) (FHIR content format) and transform it to one or more CommunicationEngine events as described in Section 2.3.

- Changes (creation/update or deletion) in the **POWER2DM Goal** resources are transformed to BehavioralGoal event
- Changes in **POWER2DM InterventionPreference** resources are transformed to **InterventionPreferenceChanged** events; latest preferences of patients (overwriting previous records)
- Changes in **POWER2DM UserSetting** resources are transformed to **SettingsChanged** events; latest settings of patients (overwriting previous records)
- Changes in **POWER2DM ActionPlan** resources that schedules something for that day are transformed to **PlannedAction events**; schedules for specific time within the day + schedules for unspecified time (but is scheduled for the day)
- Changes in **POWER2DM MedicationOrder** resources that schedules medications for that day are transformed to **PlannedAction** events where behaviour is Medication Adherence and action is specified based on the given medication

- Each new **POWER2DM Observation** or **MedicationAdministration** resources are mapped to **PatientObservation** events

FHIRRestView module also provides the necessary FHIR query mechanism to retrieve those specific records for state initialization. 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).

2.5 Behaviour Monitoring Module

As described in D3.3, this module continuously processes the stream of PatientObservation events and convert them to PerformedAction events for corresponding behaviour. It utilizes BehaviorHandler modules implemented for each behaviour to match an observation with a behaviour and make the conversion e.g. A medication intake observation into a PerformedAction of medication intake.

2.6 Intervention Planner Modules

Separate modules for reminders and motivations are unified in this new version as a single module; InterventionPlanner. It runs on the stream of Patient State snapshots (Spark Stateful Processing architecture provides a functionality to get a stream of state snapshots). Periodically, a snapshot is taken for each PatientState periodically (every 2 minutes), and InterventionPlanner runs intervention planning algorithm for each patient state given in this snapshot.

Summary of the intervention planning algorithm is as follows;

For each active BehaviorState in the PatientState;

a) Check if patient needs an intervention for his missed or performed actions in the latest passed period (i.e. last 2 minutes if period is configured as 2 minutes) by using the Intervention Decision Handler module

- If yes, find all motivational interventions available for the current patient context for the behaviour; finding the interventions that are designed for the behaviour and satisfying the conditions based on patient context
- Randomly select an intervention among the set of possible interventions
- Use BCT Handlers to customize the intervention content (i.e. fill the placeholder values) based on the BCT technique defined for the intervention
- Provide the planned intervention as output

b) Check if patient needs an intervention for planned actions in the upcoming period (i.e. next 2 minuts)

- If yes, find all reminder type interventions available for the current patient context for the behaviour
- Randomly select an intervention among the set of possible interventions
- Use BCT Handlers to customize the intervention content (i.e. fill the placeholder values) based on the BCT technique defined for the intervention
- Provide the planned intervention as output

The intervention definition language is improved in order to define more flexible interventions by defining a rule language which specifies the conditions for the interventions. The new intervention definition model is as follows;

Intervention

- **id -** Unique identifier of the intervention

- **description –** Textual description of the intervention and when it should be delivered
- **category –** Category of the intervention (reminder, motivation)
- **behaviour –** Identifier of the target behaviour that intervention is about
- **bct –** Main behavioural change technique that this intervention is using
- **rules –** Rules that are defining the conditions based on the current and past patient context to deliver this intervention
- **content –** The content of the intervention as a template with placeholders in different languages.

Figure 3 illustrates an example intervention definition which is used as one of the interventions for POWER2DM for Blood Glucose Monitoring Behaviour. This intervention is delivered when patient achieves his daily, weekly or monthly goal to motivate him.

Figure 3 An Example Intervention Definition

The rule language is simple, the format of a rule is as follows;

<Context >.<Temporal>[Index] <Operation> <Value>

Context can be either;

- Any monitored patient context configured in the system (e.g. stress, mood, etc)
- Or special contexts for the behaviors;
  - **'goal':** How well patient reaches the goal for the given behavior (See context categorization in Section 2.1)
  - **'adherence':** Overall adherence score for patient (between 0 and 1) for the behavior

Operation can be one of the followings; '=', '>', '<', '>=', '<=', '!=' which has the same mathematical meaning.

Temporal can be one of the followings;

- If **no temporal** used, it means; the value for latest behaviour action e.g. goal = 3 (for behavior BGM) → If patient adheres to latest blood glucose monitoring action plan
- **"daily"**: the given context is evaluated daily e.g. goal.daily = 3 → If patient reaches his goal for today for the behavior
- **"weekly":** the given context is evaluated weekly e.g. goal.weekly = 0 -> If patient does not achieve his goal this week
- **"monthly":** the given context is evaluated monthly
- **"best"** | **"worst"**: The best/worst value for the given context patient achieves
- **"best-day"** | **"worst-day"**: The best/worst value for a day that patient achieves e.g. goal.daily > goal.best-day : If today patient achieve better than his best day
- **"best-week"** | **"worst-week":** The best/worst value for a week that patient achieves
- **"best-month"** | **"worst-month":** The best/worst value for a month that patient achieves

Index is an integer and used as follows;

- If not used, it means; the latest temporal of the context

  - e.g. goal = 2 → For the latest action if patient reaches the goal
  - e.g. goal.daily = 2 → If patient reaches the goal today
  - e.g. goal.monthly = 2 → If patient reaches the goal this month
- If index is positive, it means the comparison should be satisfied for each of the latest values
  - e.g. goal[4] = 0 → Patient does not achieve his goals for latest 4 actions
  - e.g. stress[7] > 8 → For the last 7 stress recordings, patient has high stress (more than 8)
  - e.g. goal.daily[3] = 2 → Patient achieves his daily goals for the last 3 days
- If index is negative, it means the comparison should be satisfied for the temporal given by the index itself
  - e.g. goal.weekly[-1] = 0 → If patient does not achieve his last week goal
  - e.g. stress.monthly < stress.monthly[-2] → If this month, patient's stress is less than 2 months before on average

Value can be either a number or an expression part of the rule (left side of rule).

Rules can be joined by "and"s; where both of them should be satisfied

- e.g. goal.monthly = 2 and goal.montly[-1] = 2 → Patient reaches his goal both this month and last month

At least one of the rules in the intervention definition should be satisfied to deliver the intervention. If more than one is satisfied, the content will be evaluated according to the order of the rules.

D3.2 provides details of the placeholders and contexts used for POWER2DM JITAIs. Here we will give only an example intervention to demonstrate the evaluation of rules and placeholders. Figure 4 illustrates another example intervention from the set of POWER2DM interventions.

```
{
  "id": "BGM-MOT-GA-GR-1",
  "description": "Patient does achieve his daily or
weekly BG monitoring goal successively, so we
motivate him for this success",
  "category": "motivation",
  "behaviour": "monitor_bgm",
  "bct": "gr",
  "rules": ["goal.weekly = 3 and goal.weekly[1] = 3",
"goal.daily = 3 and goal.daily[2] = 3"],
  "content": {
    "en": "Congratulations, you successively achieved
your goal for last ${streak_value}
${streak_temporal}s."
  }
}
```

Figure 4 An Example Intervention Definition; Placeholder and Rule Evaluation

Here we have 2 rules for this intervention where either should be satisfied to deliver it;

- Rule 1 → If patient reaches his Blood Glucose Monitoring goal this week and also he achieves his goal for last week (at least 2 successive)
- Rule 2 → If patient reaches his goal today also achieves goal for the last two days (at least 3 successive)

BCT technique for this intervention is stated as GR (General Reinforcement), and GR supports several placeholder usages where "streak_value" and "streak_temporal" are the ones that are used to check successive achievements or failure of the patient.

For example, if Rule 1 is satisfied, but patient is reaching his goal for the last 4 weeks then the intervention becomes**;** "Congratulations, you successively achieved your goal for last 4 weeks".

But, if rule 1 is not satisfied and Rule 2 is satisfied, and patient reaches his goal (goal context is 3) for the last 3 days, then the intervention to be delivered is "Congratulations, you successively achieved your goal for last 3 days".

If none of the rules are satisfied, then the intervention is not within the list of possible interventions for that execution.

2.6.1 Intervention Decision Handler

As described in Section 2.1, InterventionDecisionHandler is implementing the simple approaches for i) decision to intervene or not, ii) selecting an intervention among available ones and iii) planning the time for intervention, although it is possible to extend to more complex mechanism as described in our publication "An Expandable Approach for Design and Personalization of Digital, Just-In-Time Adaptive Interventions".

For the latest Prototype 2 and 3, the followings are the summary of these simple mechanisms;

i) **Decision to intervene or not;** Check if there is a missed or performed action for the last period or planned action for the upcoming period and if exist decide to intervene with the probability given by the patient's intervention preference for the behaviour and category

ii) **Selecting an intervention among available ones;** Randomly select an intervention among the set

iii) **Planning the time for intervention;** Immediately deliver the intervention

2.6.2 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. CommunicationEngine uses the topic based delivery option which is sending a message to a topic where subscribers to that topic received the notification. The basics of the mechanism is as follows;

- When patient logins from the POWER2DM Mobile Application, application sends the push notification token to the special PDS service, RegisterDeviceToken service with the patient identifier e.g. https://app.srdc.com.tr/power2dm/pds/Patient/<pid>/$register-device-token?token=.....
- The service subscribes this token to the topic "interventions-<pid>".
- Then when CommunicationEngine need to deliver an intervention it sends the intervention to the topic "interventions-<pid>" by using the patient identifier. In this way, only that patient receives the message but he can receive this message from his multiple devices.

Notification parameters are as follows;

- **to:** Refers the topic to send the notification e.g. /topics/interventions-<pid>
- **notification:**
  - **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
- **data:** Data payload parameters;
  - **pid:** Patient identifier
  - **time:** Time until this intervention is valid

3 TESTING AND DEMONSTRATIONS

For POWER2DM, 120 interventions (JITAIs) are defined by behavior change experts to be used in Evaluation Campaign for 5 major behaviors (Blood Glucose Monitoring, Exercise Monitoring, Carb

Monitoring, Steps Monitoring, Medication Adherence and KADIS 3-day Data Collection) and KADIS 3-day Data Collection as illustrated in D3.2. These intervention designs are documented in an excel file collaboratively and can be accessible from https://docs.google.com/spreadsheets/d/17ji1-fkh7TJchDbuEUVAfEUCY0c2g4o7n0gg34yer4c/edit?usp=sharing . All interventions are available for Spanish, Ducth and English.

These intervention designs are transformed into the CommunicationEngine's intervention definition language and embedded in the setup for CommunicationEngine;

- Blood Glucose Monitoring Behavior → bgm_jitais.json
- Medication Adherence Behavior → med_adherence_jitais.json
- Carbohydrate Monitoring Behavior → carb_monitoring_jitais.json
- Physical Activity Behavior → exercise_jitais.json
- Steps Monitoring Behavior → steps_jitais.json
- KADIS 3-Day Data Collection Behavior → kadis_jitais.json

3.1 Testing Platform and Activities

It is difficult to test and 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, for testing we have developed a special "debug" mode for the execution of CommunicationEngine which enables it to work on retrospective data stored in PDS by simulating the data stream from the data and can be configured to speed up the execution (e.g. 1 hour in real life is executed in 1 seconds). In this mode, CommunicationEngine can be started at a retrospective time according to created data in PDS, and it periodically retrieves data from PDS to create the data stream.

Also, a test data generator component is implemented to create logical test data to test CommunicationEngine and JITAIs designed for POWER2DM. This test data generator, based on the configurations, creates treatment and self-management plans for a patient for a specific behavior. Again, based on the configurations that describes a simulated performance of patient for that behavior, it creates the corresponding Observation resources. For example, with this component we can create 5 patient profiles each having set the same behavioral goal and action plans (e.g. Blood Glucose Monitoring before meals) but have different adherence performance ranging from very bad to very good. For all the behaviors supported in POWER2DM for JITAIs, data generator scripts are implemented in this way.

Finally, a web-based Notification Viewer application is implemented just for test purposes to monitor the notifications received for a set of patients with specified patient identifiers.

3.1.1 Tests of JITAIs for each behaviour

Using the test setup described above, for each behavior supported for JITAIs (Blood Glucose Monitoring, Exercise Monitoring, Carb Monitoring, Steps Monitoring, Medication Adherence and KADIS 3-day Data Collection), test data (for 2 month period) is created for a set of patient profiles ranging from low adherence performance to high adherence performance. Then CommunicationEngine is executed on this data in debug mode together with Notification Viewer to list the interventions that these patients with different behavioral adherence performance are receiving.

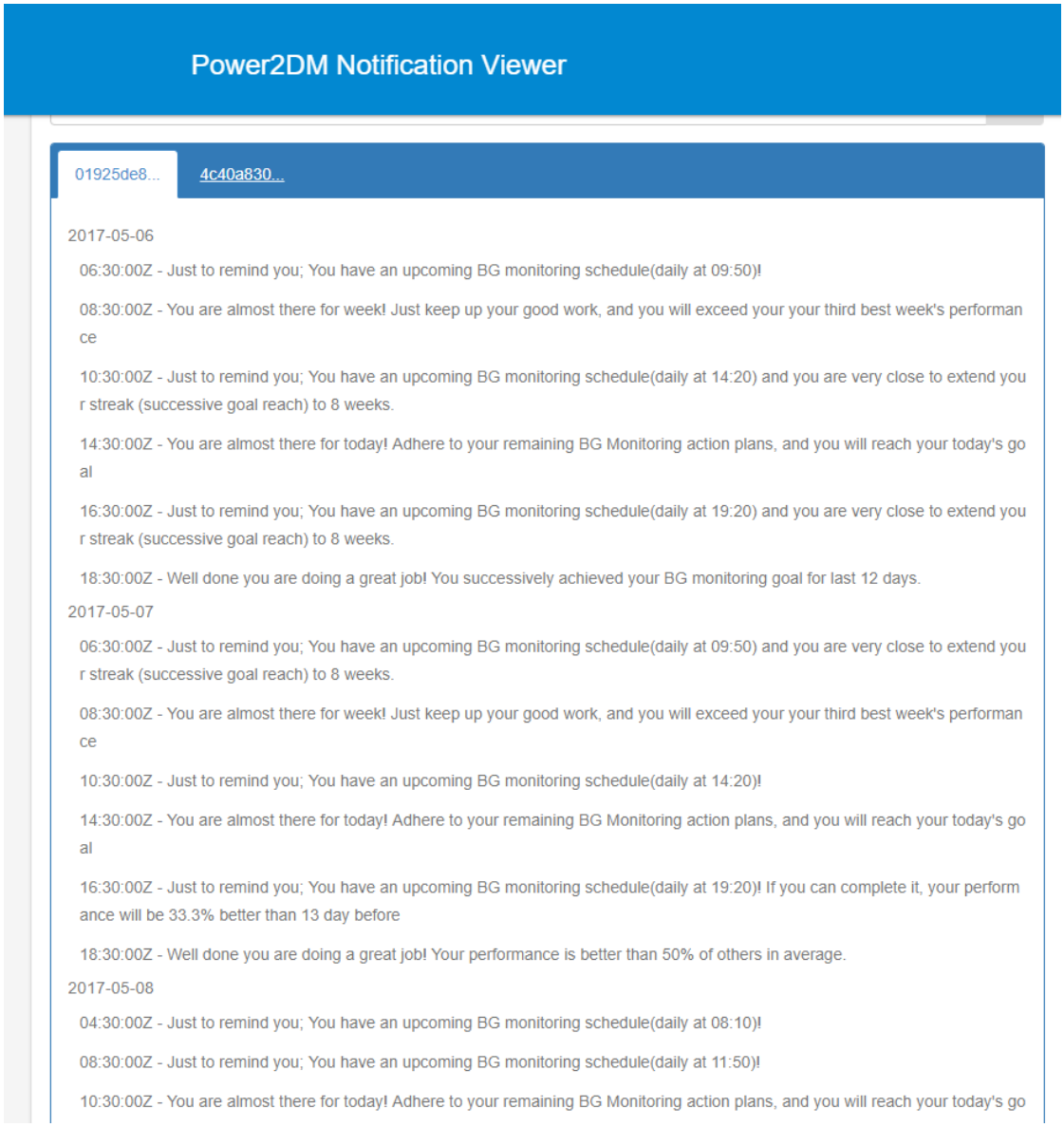

Figure 5 Example interventions received by a patient with good BG monitoring adherence

Figure 5 illustrates a snapshot from NotificationViewer taken during the tests, for a patient profile which has good Blood Glucose Monitoring Adherence. Similarly, **Figure 6** illustrates the interventions received by a patient profile with low BG monitoring adherence.

All the received interventions for each patient profile are copied to Word documents and shared with clinicians and behaviour change experts from piloting partners LUMC and SAS to enable them to check the language, and logic one more time. One of such example files is given in the Section 4.1 in Appendix A.

Figure 6 Example interventions received by a patient with low BG monitoring adherence

3.2 Demonstration

In POWER2DM test environment, we have created 3 test patient profiles for the demonstration of CommunicationEngine and JITAIs. The followings are the descriptions of these patient profiles;

Patient Profile I	
Username	srdc_patient21
Password	password
Self-management Goal	Monitoring his blood glucose every day between “08:30-09:00”, “12:00-12:30”, and “18:00-18:30”.
Patient Profile II	
Username	srdc_patient22
Password	password

Self-management Goal	Log his carbohydrate intakes after meals; breakfast: 08:30-09:30, lunch: 12:00 – 12:30 and 18:00-19:00
Patient Profile III	
Username	srdc_patient23
Password	password
Self-management Goal	Walk 1 hour 4 times a week; Monday between 14:00-15:00, Tuesday between 15:00-16:00, Wednesday between 16:00-17:00 and Thursday between 13:00-14:00

For this demo, you can download the POWER2DM Mobile Application from the address https://ihealthnext.eu/power2dm/ and install it to your phone according to instructions (This is the version configured for POWER2DM Test Environment). Then choose one of the patients and login with the patient account and use the application 1 or more days to receive push notifications based on the planned actions for that patient. So, for example, for Patient Profile I, you will receive reminder messages before the scheduled times. Based on whether you log your blood glucose measurement from the mobile application or not you may receive a motivational message either motivating for successful completion of task or motivating even missing an action.

Please note that all these patients are registered as English so language of the interventions will be English and also the time zone for evaluation is also for UTC. Please contact with the author of deliverable, if you have problem with the demonstration. POWER2DM Test Environment is generally up and running but problems may occur due to maintenance tasks.

4 APPENDICES

4.1 Appendix A – Sample interventions received by a patient profile generated for test

Patient Profile (Test Data):

- **Goal/Action Plan:** 2 times Carb monitoring for breakfast and dinner and manage low carb (lower than 29.5 g per meal)
- %80 adherence carb logging
- **Carb Amount Taken:** Mean: 22g, Std. Deviation: 16 (So few times it is medium carb)
- Time Zone: +2
- Weekdays → Wake-up: 7:30, Breakfast: 08:00, Lunch: 12:00, Dinner: 18:30, Sleep: 23:59
- Weekends → Wake-up: 9:30, Breakfast: 10:00, Lunch: 14:00, Dinner: 20:00, Sleep: 00:30

JITAIs delivered

2017-10-02

- 06:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met ontbijt [~ om 08:00]).
- 08:30:00Z - Goed gedaan! je hebt je doel bereikt om te Het bijhouden/monitoren van koolhydraten bij de afgelopen 3 maaltijden.
- 16:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met diner [~ om 18:30]).
- 18:30:00Z - Goed gedaan! Je hebt je doel bereikt voor deze/dit dag.

2017-10-03

- 06:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met ontbijt [~ om 08:00]).
- 07:30:00Z - Heel goed! Je hebt je doel bereikt om te Het bijhouden/monitoren van koolhydraten bij de vorige maaltijd.

- 16:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met diner [~ om 18:30]).
- 17:30:00Z - Dat was een goede dag, je bent 25.5% beter dan laatste zondag in Het bijhouden/monitoren van koolhydraten.

2017-10-04

- 06:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met ontbijt [~ om 08:00]).
- 09:30:00Z - Het lijkt erop dat je vergeten bent de hoeveelheid koolhydraten in te voeren voor je laatste maaltijd. Als het lukt om de resterende doelen/activiteiten voor vandaag te behalen, ben je nog altijd dicht bij het bereiken van je doel.
- 16:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met diner [~ om 18:30]).
- 18:30:00Z - Jammer dat het vandaag niet is gelukt! Morgen is misschien een betere dag!

2017-10-05

- 06:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met ontbijt [~ om 08:00]).
- 07:30:00Z - Goed gedaan! je hebt je doel bereikt om te Het bijhouden/monitoren van koolhydraten bij de afgelopen 3 maaltijden.
- 16:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met diner [~ om 18:30]).

2017-10-06

- 06:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met ontbijt [~ om 08:00]).
- 07:30:00Z - Klopt het dat je je doel om weinig koolhydraten te eten bij je laatste maaltijd niet hebt kunnen behalen? Als het lukt om de resterende doelen/activiteiten voor vandaag te behalen, dan ben je nog altijd dicht bij het bereiken van je doel.
- 16:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met diner [~ om 18:30]).
- 18:30:00Z - Heel goed! Je prestaties zijn beter dan 66% van (de) anderen gemiddeld.

2017-10-07

- 08:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met ontbijt [~ om 10:00]).
- 09:30:00Z - Goed gedaan! je hebt je doel bereikt om te Het bijhouden/monitoren van koolhydraten bij de afgelopen 3 maaltijden.
- 18:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met diner [~ om 20:00]).
- 20:30:00Z - Dat was een goede dag, je bent 21.0% beter dan laatste 3 dagen in Het bijhouden/monitoren van koolhydraten.

2017-10-08

- 08:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met ontbijt [~ om 10:00]).
- 09:30:00Z - Heel goed! Je hebt je doel bereikt om te Het bijhouden/monitoren van koolhydraten bij de vorige maaltijd.
- 18:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydraten gepland op/om (dagelijks met diner [~ om 20:00])! Als je die voltooit, dan doe je het ???% beter dan anderen deze week.
- 21:30:00Z - Je hebt het doel week bijna gehaald! Je prestaties zijn beter dan 33% van de anderen deze week.

2017-10-09

- 06:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met ontbijt [~ om 08:00]).
- 08:30:00Z - Goed gedaan! je hebt je doel bereikt om te Het bijhouden/monitoren van koolhydraten bij de afgelopen 3 maaltijden.
- 18:30:00Z - Goed gedaan! Je hebt je doel bereikt voor deze/dit dag.

2017-10-10

- 06:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met ontbijt [~ om 08:00]).
- 07:30:00Z - Klopt het dat je je doel om weinig koolhydraten te eten bij je laatste maaltijd niet hebt kunnen behalen? Als het lukt om de resterende doelen/activiteiten voor vandaag te behalen, dan ben je nog altijd dicht bij het bereiken van je doel.
- 16:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met diner [~ om 18:30]).
- 18:30:00Z - Goed gedaan! Je hebt je doel bereikt voor deze/dit dag.

2017-10-11

- 06:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met ontbijt [~ om 08:00]).
- 07:30:00Z - Heel goed! Je hebt je doel bereikt om te Het bijhouden/monitoren van koolhydraten bij de vorige maaltijd.
- 16:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met diner [~ om 18:30]).
- 20:30:00Z - Jammer dat het vandaag niet is gelukt! Morgen is misschien een betere dag!

2017-10-12

- 06:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met ontbijt [~ om 08:00]).
- 08:30:00Z - Goed gedaan! je hebt je doel bereikt om te Het bijhouden/monitoren van koolhydraten bij de afgelopen 3 maaltijden.
- 16:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met diner [~ om 18:30]).
- 20:30:00Z - Jammer dat het vandaag niet is gelukt! Morgen is misschien een betere dag!

2017-10-13

- 06:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met ontbijt [~ om 08:00]).
- 07:30:00Z - Goed gedaan! je hebt je doel bereikt om te Het bijhouden/monitoren van koolhydraten bij de afgelopen 3 maaltijden.
- 16:30:00Z - Om je te helpen herinneren; je hebt een activiteit Het bijhouden/monitoren van koolhydratengepland op/om (dagelijks met diner [~ om 18:30]).
- 20:30:00Z - Jammer dat het vandaag niet is gelukt! Morgen is misschien een betere dag!