CONNECARE

Seminar
Autonomous Systems 17/18
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Decision Support Systems for Integrated Care of Complex Chronic Patients

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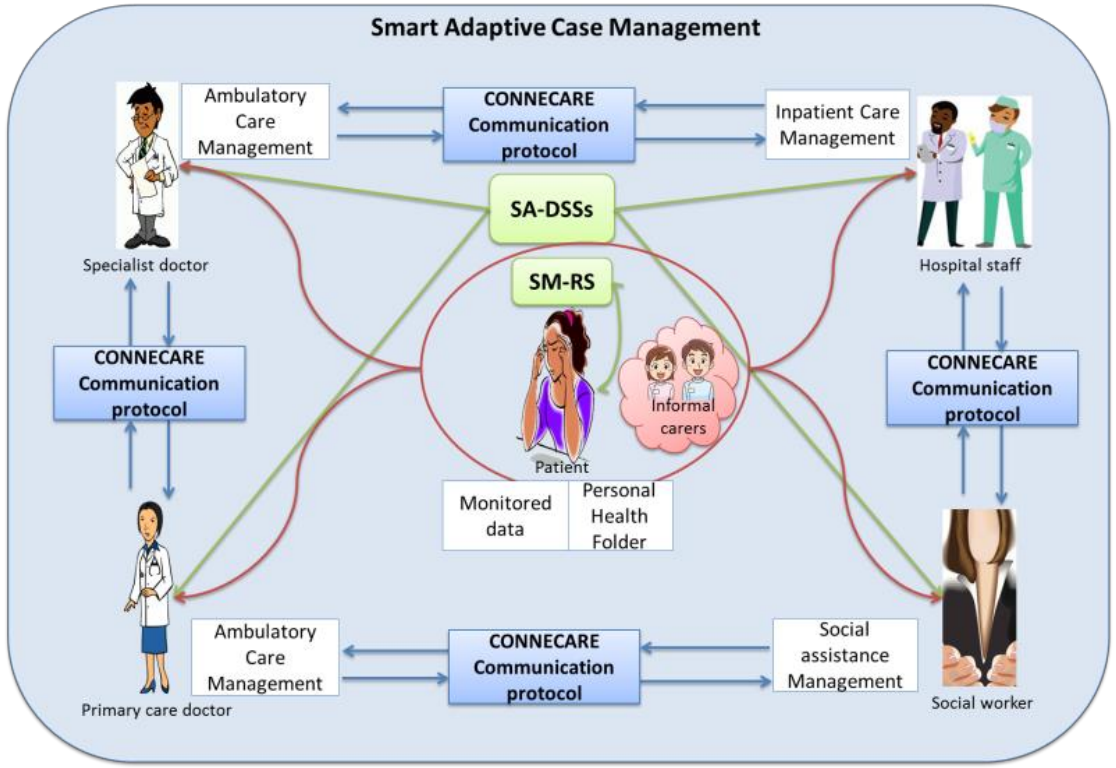
What is CONNECARE?

- European project
  - call: https://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/phc-25-2015.html
  - type: Research and Innovation Action (RIA)
  - topic: Advanced ICT systems and services for integrated care
  - funding framework: H2020

- **“Personalised Connected Care for Complex Chronic Patients”**
  - web page: http://www.connecare.eu/
  - consortium: 2 universities, 3 research institutions, 2 hospitals, 2 companies, spread across 6 countries
  - funding amount: ~ 5 billions (€)

- Goals:
  - novel *smart* and *adaptive* organisational *integrated care* model for *complex chronic* care management
  - **decision support** for the adaptive management of *personalised clinical pathways*
  - **recommendations** to let patients *self-manage* their condition
  - *clinical trials* to assess the approach and favour adoption
  - advance state of art in *4P medicine* (predictive, preventive, personalised, and participatory)

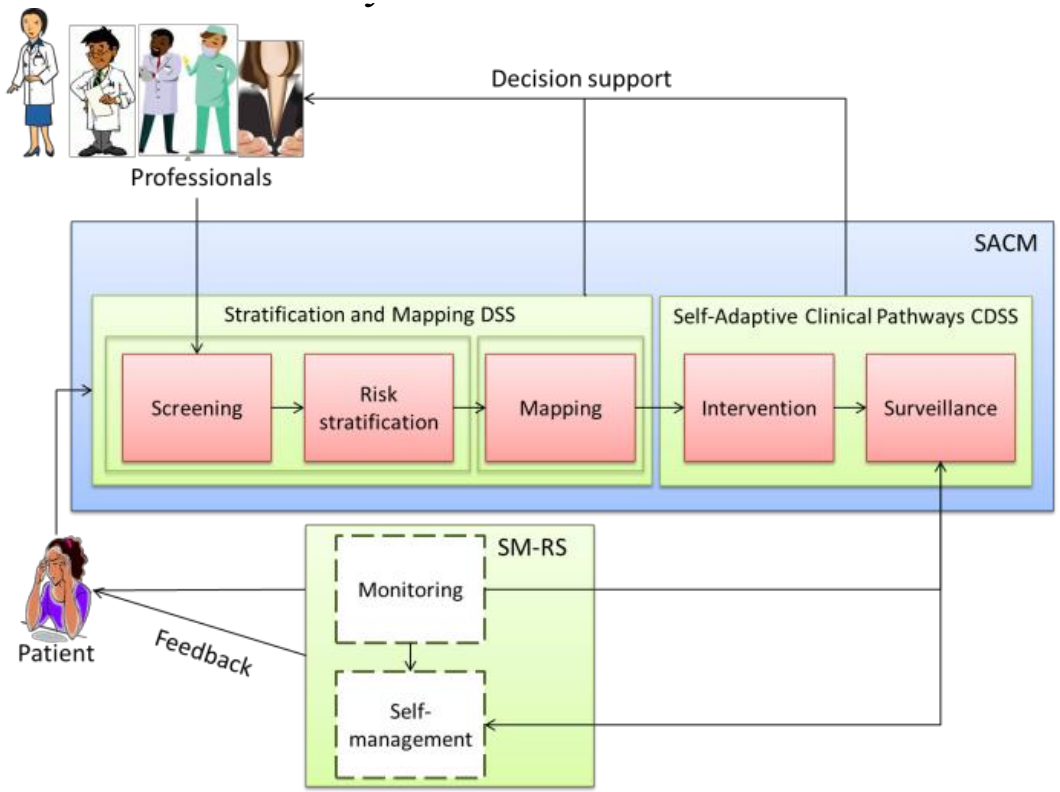
- **Integrated care**:
  - *defragmentation* of health and social care systems
  - promotion of *collaboration* and continuity among care settings
  - from institutional, reactive care to a home-based, *patient-centred*, *preventive* model
- *3 dimensions*:
  - organisational
  - social
  - technological



- **Complex Chronic Patient**:
  - > 1 chronic diseases
  - comorbidities
  - frail (due to social, economic and/or clinical factors)
  - usually elderly
  - who consumes a very high level of health resources

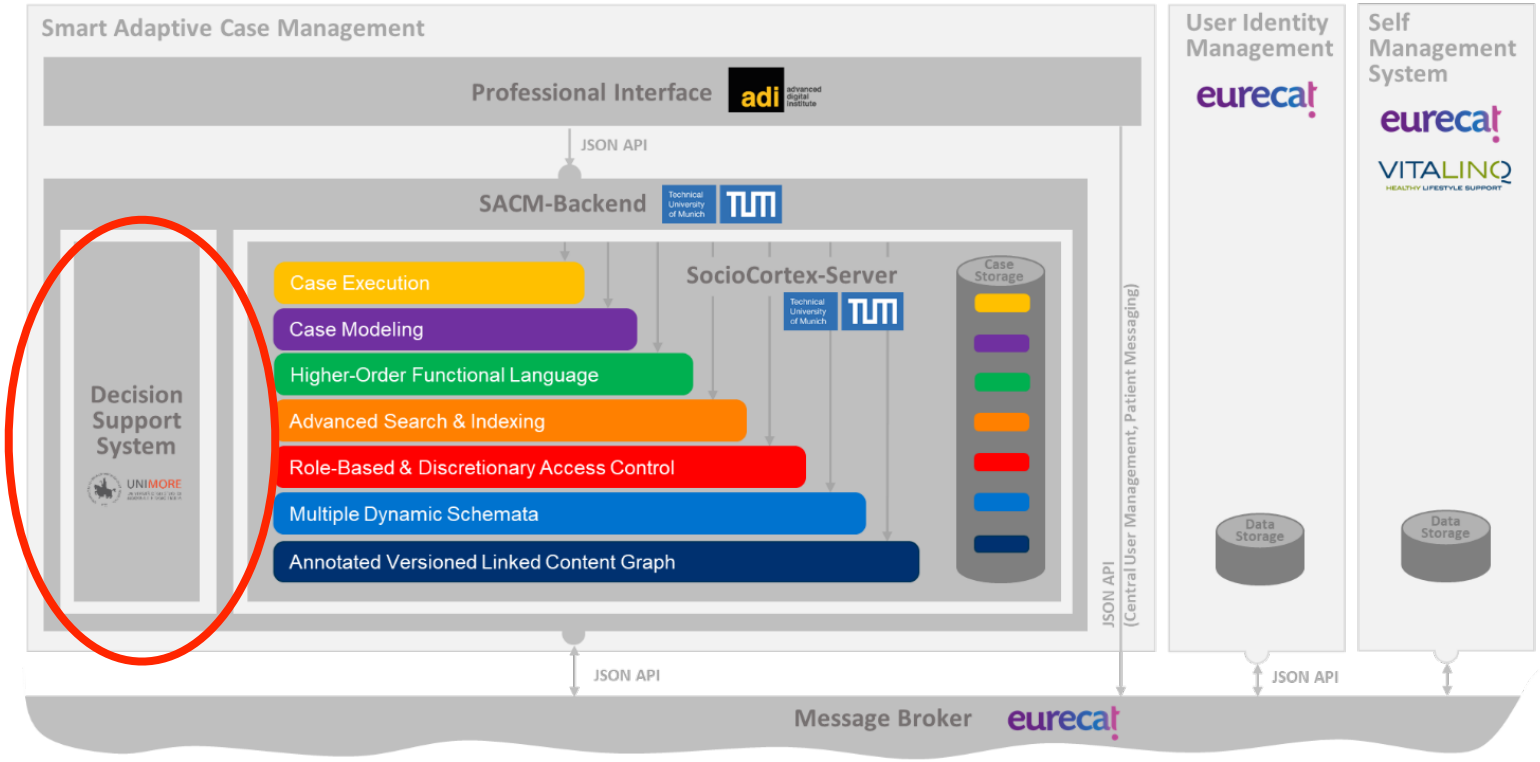
- *EU numbers* (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hlth_silc_05&lang=en):
  - CCP's health status is suffered by about 5% of the general population
  - 20-40% of all hospital admissions are CCPs
  - > 40% of health resources consumed

- **Smart** and **adaptive** care:
  - *risk stratification* based on state of art stratification algorithms (e.g., GMA, CRG)
  - *mapping* to correlate the patients' geographical location with the health care resources available
  - *clinical pathways* planned based on risk stratification and mapping
- **Self-management**:
  - monitoring
  - *recommendations*

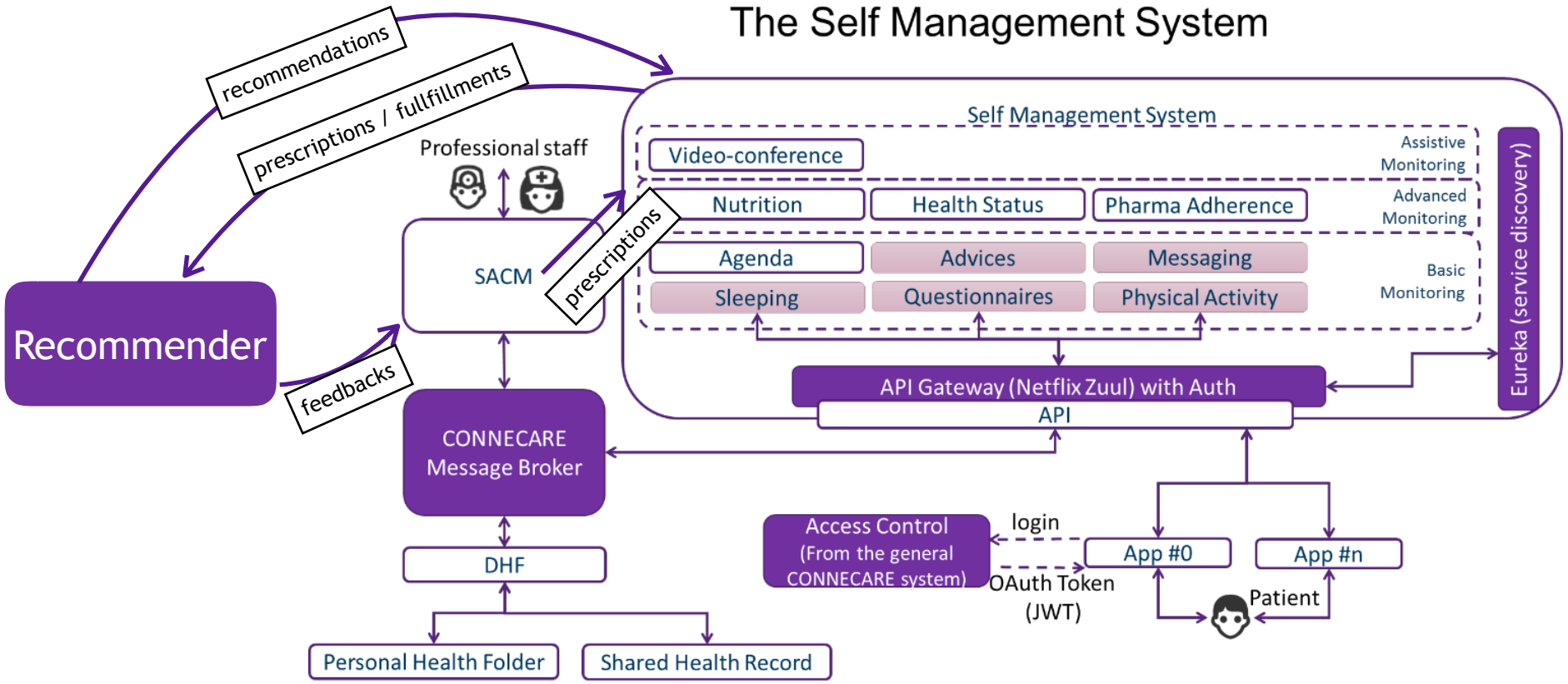


- **SACM** (= Smart Adaptive Case Management)
  - implementation of the CONNECARE approach to *Adaptive Case Management* (= *flexible* handling of patient-centred care processes)
  - "flexible" = programmable (the process) by non-programmers

- "smart" = ACM + **CDSS**



- **SMS** (= Self-Management System)
  - implementation of the CONNECARE approach to *personalised medicine* and *patient empowerment*
  - towards *patient-centred care*



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The Clinical Decision Support System

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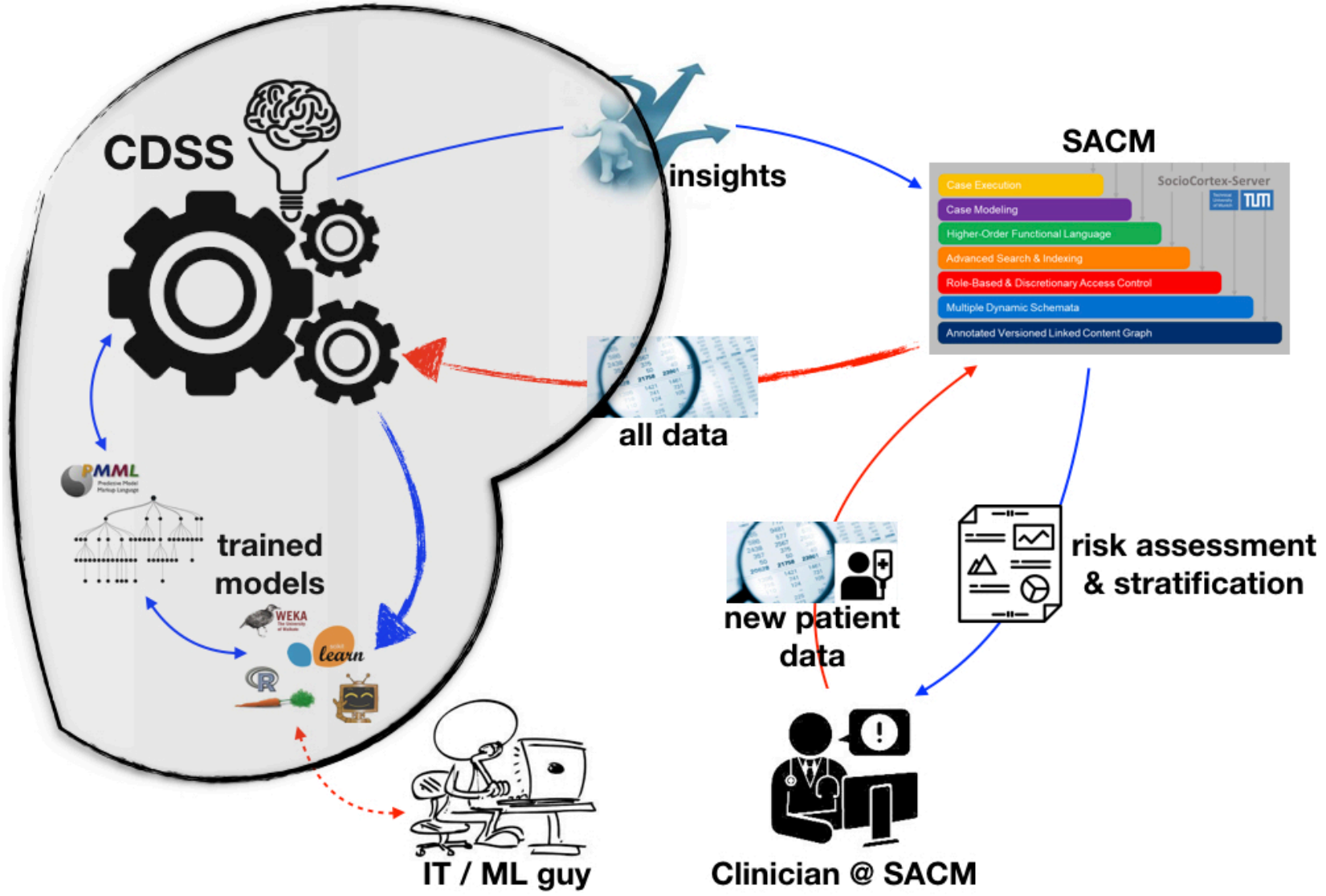
The Clinical Decision Support System

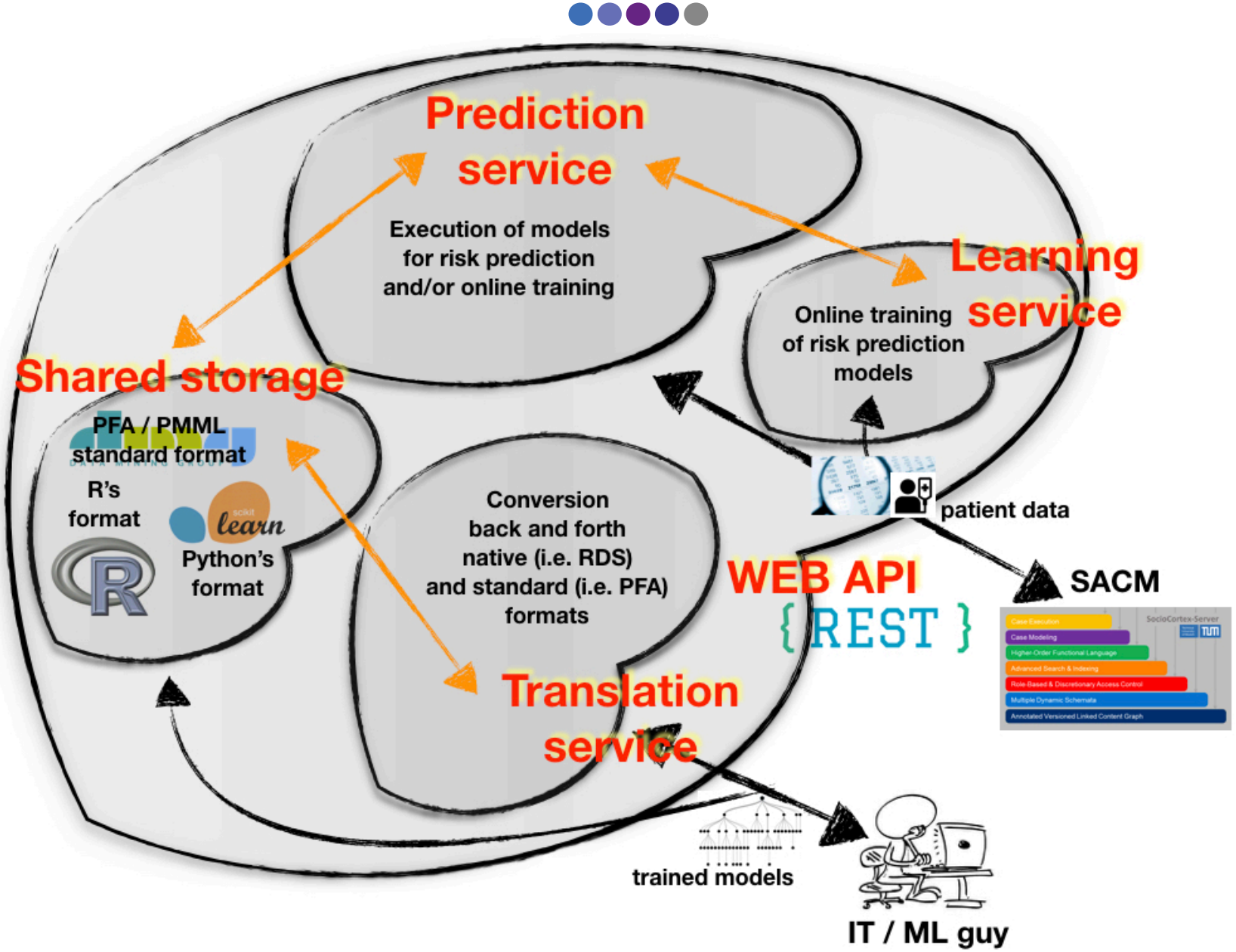
Risk assessment

- **Motivations**:
  - paradigm shift towards *predictive* and *personalised* medicine —> new computational requirements for predictive modelling
  - *rule-based systems* for clinical management accepted in clinical practice
  - exploitation of *predictive modelling* still far from reaching maturity
  - European Union study on Big Data in Public Health, Telemedicine, and Healthcare identifies opportunities for improvement
    - *standards* and protocols
    - **technological development**
    - data *analytics*
    - (https://ec.europa.eu/digital-single-market/en/news/study-big-data-public-health-telemedicine-and-healthcare)

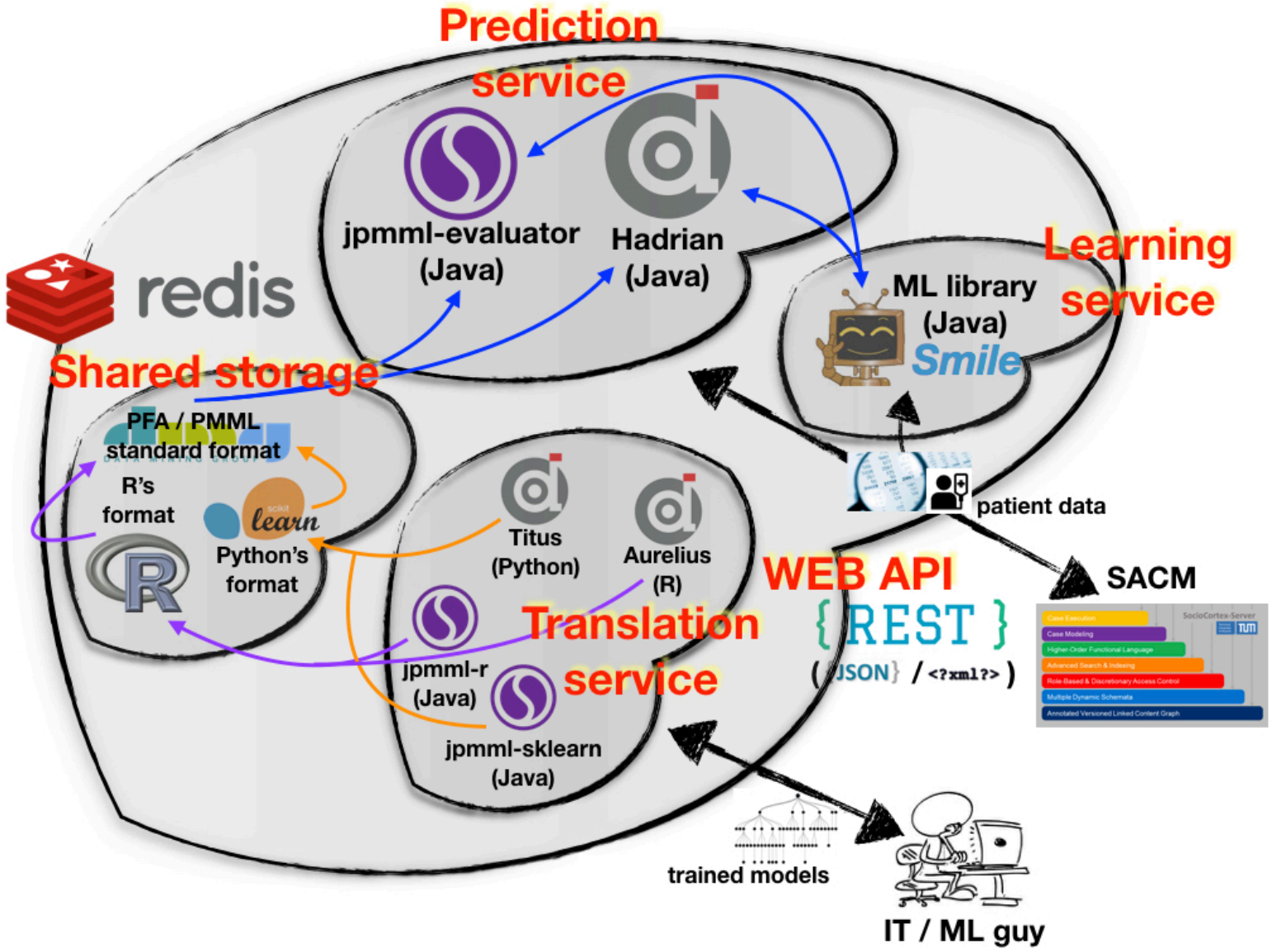
- **Goals**:
  - *accessibility* from clinicians' workstations
  - flexibility of *licensing* policy and software (re)configuration
  - openness to *iterative software improvement*
  - **separation of concerns**
    - data scientists build prediction models *offline*
    - when model ready (= evaluated) *upload* to CDSS
    - clinicians *apply* model to patients' data from web app
- **Benefits**:
  - *independent* development vs. deployment of predictive models
  - *easily* integrate novel models in production environment
  - development of models in *different programming languages* and toolkits regardless of production environment
    - i.e. caret for R, scikit-learn for Python vs. Java


CDSS
insights
SACM
Case Execution
Case Modeling
Higher-Order Functional Language
Advanced Search & Indexing
Role-Based & Discretionary Access Control
Multiple Dynamic Schemata
Annotated Versioned Linked Content Graph
SocioCortex-Server
all data
PMML
trained models
WEKA
learn
new patient data
risk assessment & stratification
IT / ML guy
Clinician @ SACM

- **data scientist**
  - upload / download / modify / delete risk prediction models
  - upload datasets meant for training / testing / application
  - download prediction results
- **clinician**
  - get predictions of selected events (i.e. re-admission, mortality) by selected available models
- **SACM**
  - trigger the CDSS to make a prediction using a selected model
  - lend to the CDSS the data it needs
  - get from the CDSS the prediction to be written back to the patient data
- **CDSS**
  - train / test / apply models

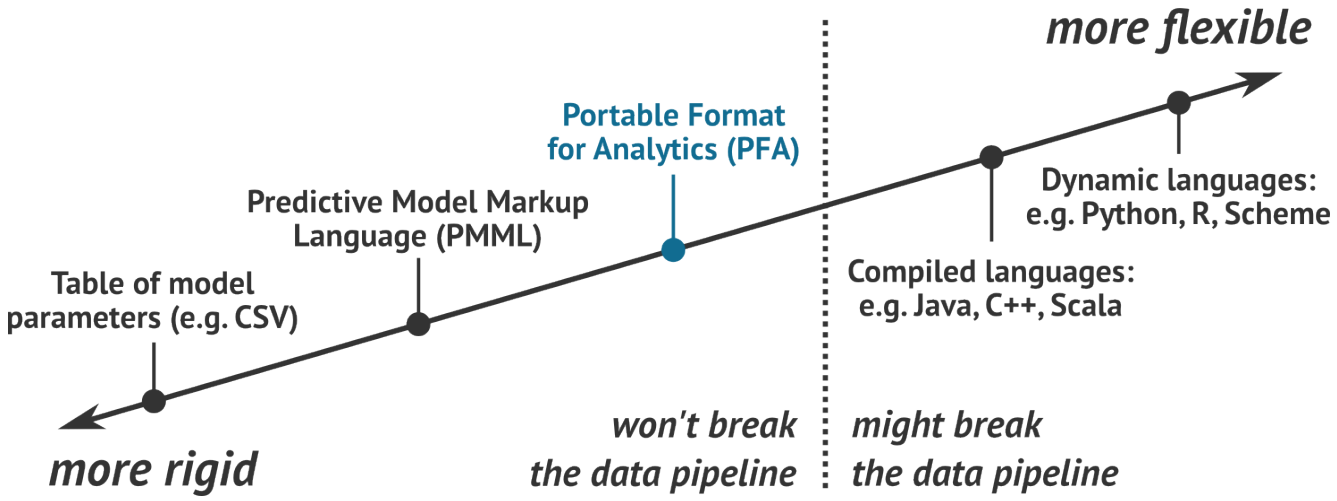

Prediction service
Execution of models for risk prediction and/or online training
Learning service
Online training of risk prediction models
Shared storage
PFA / PMML standard format
R's format
Python's format
Conversion back and forth native (i.e. RDS) and standard (i.e. PFA) formats
Translation service
patient data
WEB API
{ REST }
SACM
trained models
IT / ML guy

- **Web API**
  - *RESTful endpoint* the other CONNECARE sub-systems
- **Translation Service**
  - translation between *representation formats* of prediction models, i.e. automatic translation to **PMML** and **PFA** of models in R or Python
- **Prediction Service**
  - predictions based on models fed with supplied input data
- **Learning Service**
  - enabling the CDSS to *build* its own risk prediction models based on patient data available in the SACM
  - may get feedback from prediction service (i.e. predictions for training)
- **Shared Storage**
  - data and meta-data for CDSS execution
  - *excluded* the patient data into the SACM


Prediction service
jpmml-evaluator (Java)
Hadrian (Java)
redis
Shared storage
Learning service
ML library (Java)
Smile
PFA / PMML standard format
R's format
Python's format
Titus (Python)
Aurelius (R)
jpmml-r (Java)
jpmml-sklearn (Java)
Translation service
patient data
WEB API
{ REST }
(JSON } / <?xml?>)
SACM
trained models
IT / ML guy

- **JSON** / **XML** for patient data and metadata
- **PMML** / **PFA** to represent prediction models
  - XML / JSON based representation formats for predictions models
  - PFA supersedes PMML but still in development
  - *interoperability* between language / toolkits
  - 3rd party libraries for conversion
    - i.e. jpmml-r from R to PMML, Titus from Pyhton to PFA
- *Smile Java library* for training models
- *Redis DB* for storing models and metadata
  - in-memory
  - key-value pairs (modelUUID-model)
  - replication
  - configurable persistency

- "**Machine Learning as a Service**" (MLaaS) paradigm ("MLaaS: Machine Learning as a Service", doi: 10.1109/ICMLA.2015.152)
- Share not data but "*black-box*" models (already trained)
- PMML / PFA standards promote seamless exchange and deployment of machine learning applications
  - support *any* kind of machine learning / statistical model (i.e. regression, classifiers, clustering, etc.)
  - *models are built once, and then "run" everywhere* (http://dmg.org/pfa/docs/motivation/)



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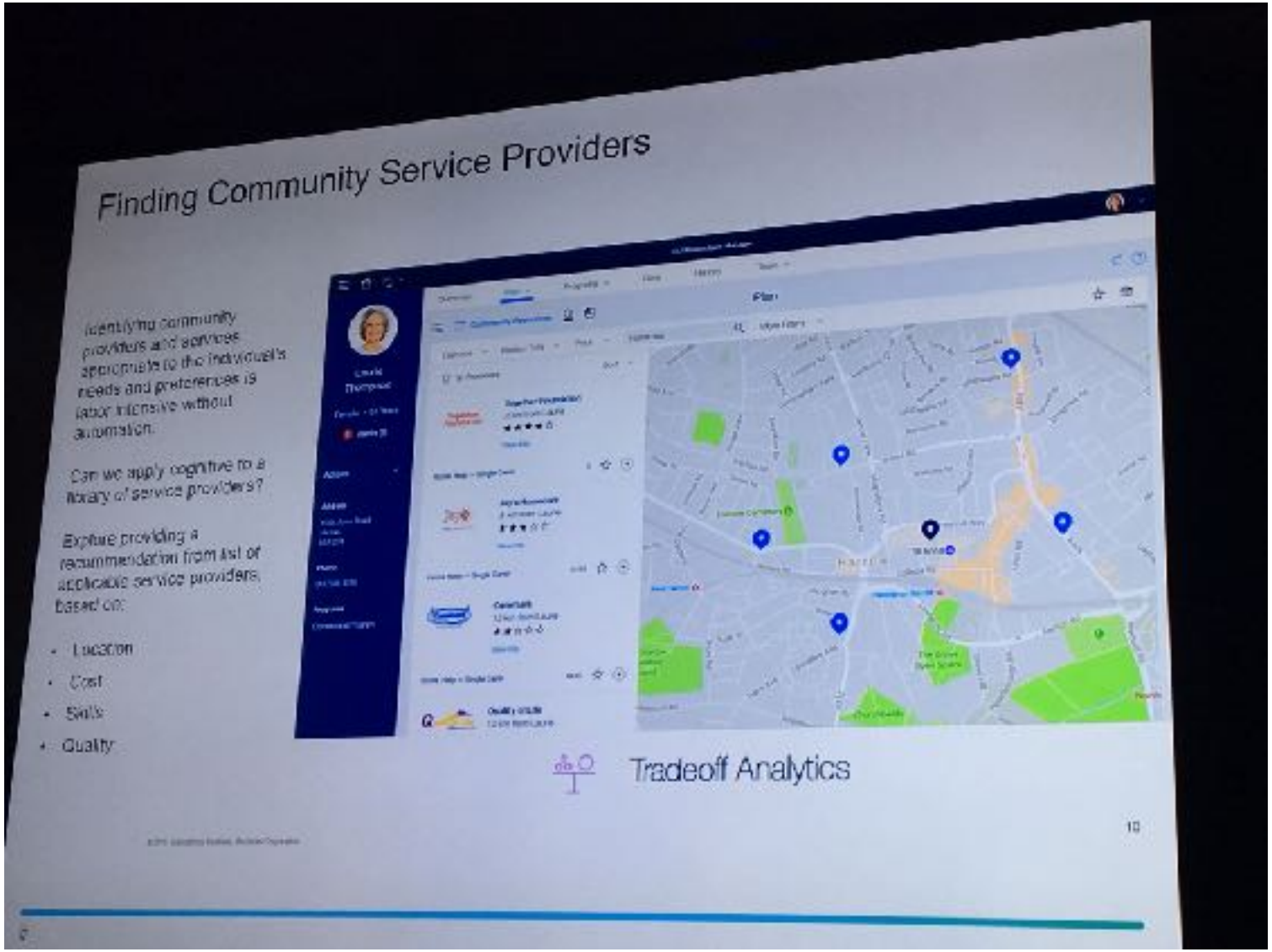
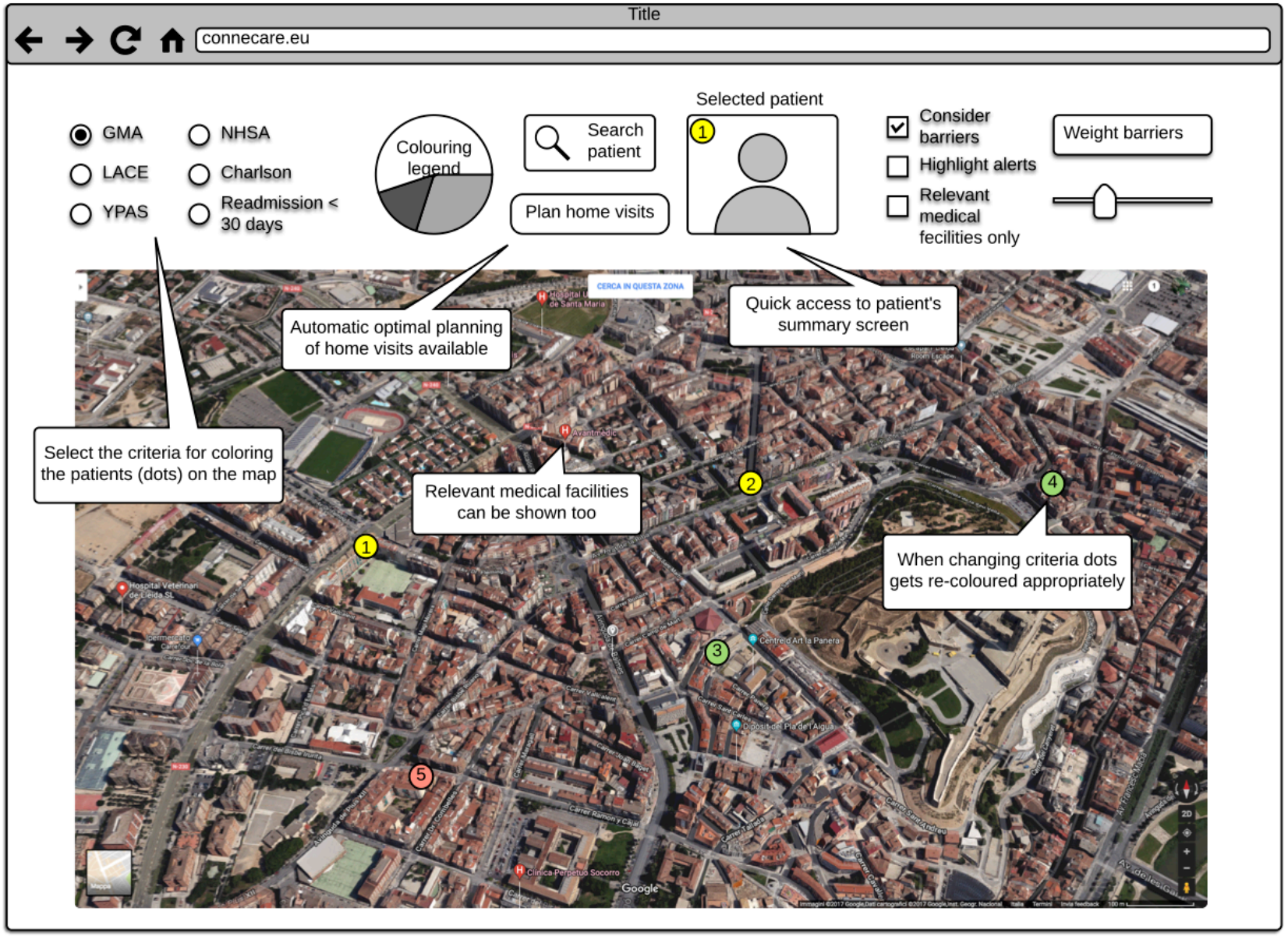
The Clinical Decision Support System

Mapping

- **Motivations**:
  - lack of "*global view*" on patients' status for clinicians
  - identifying *relevant* medical facilities is hard without automation
- **Goals**:
  - facilitate patients' *monitoring* by clinicians
  - support *planning* of home visits by nurses




Title
connecare.eu
GMA
LACE
YPAS
NHSA
Charlson
Readmission < 30 days
Colouring legend
Search patient
Plan home visits
Selected patient
Consider barriers
Highlight alerts
Relevant medical fecilities only
Weight barriers
Automatic optimal planning of home visits available
Quick access to patient's summary screen
Select the criteria for coloring the patients (dots) on the map
Relevant medical facilities can be shown too
When changing criteria dots gets re-coloured appropriately
1
2
3
4
5
CERCA IN QUESTA ZONA
Google

- **Must-have**:
  - locate patients on a map
  - render patients differently depending on selected clinical metric
  - render patients differently depending on whether they have active alerts
  - locate medical facilities on a map

- **Nice-to-have**:
  - locate also patients' relatives / caretakers
  - highlight medical facilities relevant to selected patient
  - automatic planning of home visits

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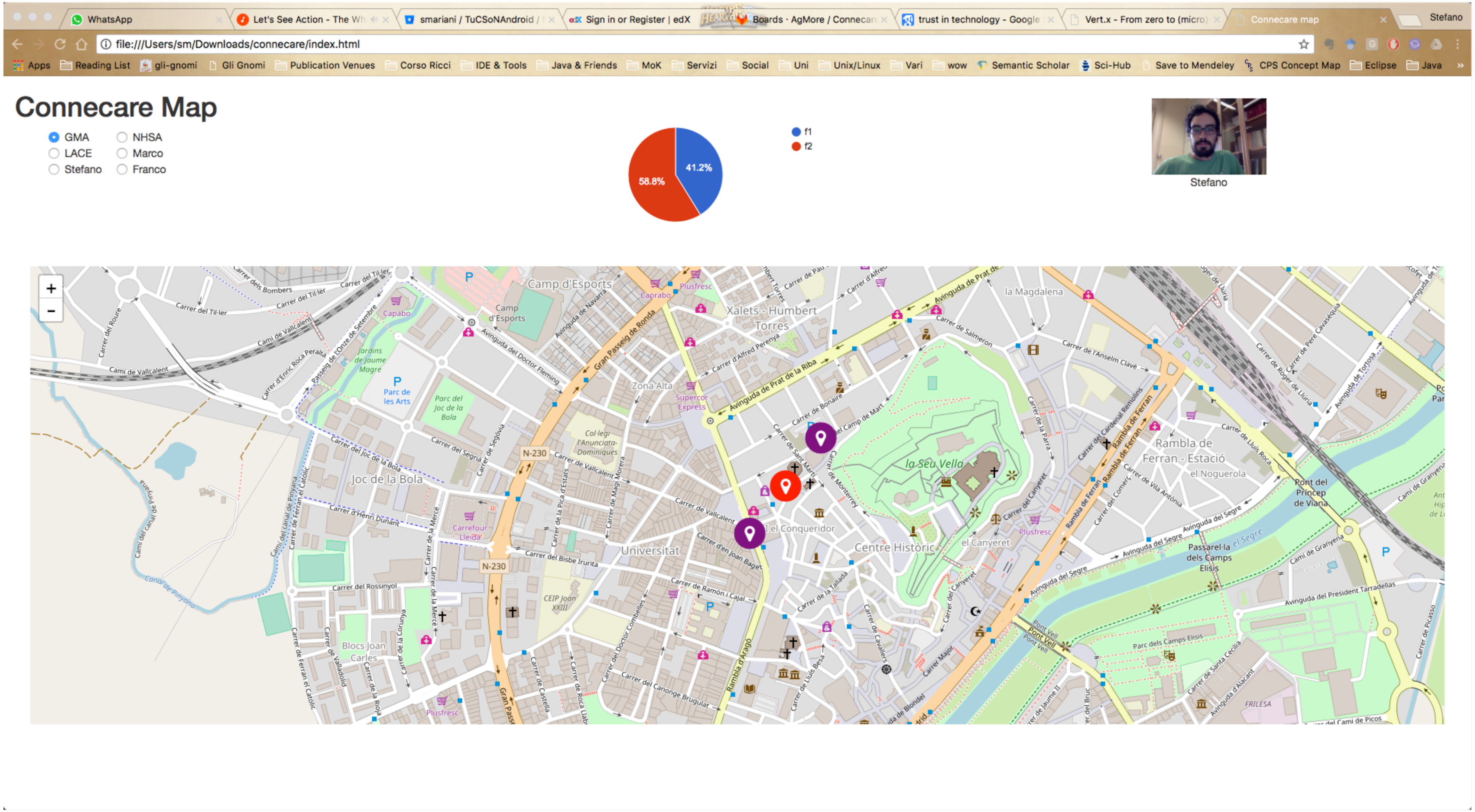
WhatsApp
Let's See Action - The Wh
smariani / TuCSoNAndroid
Sign in or Register | edX
Boards · AgMore / Connecare
trust in technology - Google
Vert.x - From zero to (micro)
Connecare map
Stefano
file:///Users/sm/Downloads/connecare/index.html
Apps
Reading List
gli-gnomi
Gli Gnomi
Publication Venues
Corso Ricci
IDE & Tools
Java & Friends
MoK
Servizi
Social
Uni
Unix/Linux
Vari
wow
Semantic Scholar
Sci-Hub
Save to Mendeley
CPS Concept Map
Eclipse
Java
Connecare Map
GMA
NHSA
LACE
Marco
Stefano
Franco
41.2%
58.8%
f1
f2
Stefano
Camp d'Esports
Xalets - Humbert Torres
Zona Alta
Joc de la Bola
Universitat
la Seu Vella
Centre Històric
Rambla de Ferran - Estació
el Canyeret
la Magdalena
N-230

- The map is provided by **Open Street Map API**
  - map rendering (i.e. http://leafletjs.com/)
  - geocoding (i.e. https://nominatim.openstreetmap.org/)
  - navigation (i.e. https://www.graphhopper.com/)
  - also *on-premise* (which overcomes usage limits)

- **Google Maps** API is another option
  - Free usage
  - 2,500 free requests per day
  - 50 requests per second
  - Subscriptions available (https://developers.google.com/maps/premium/usage-limits)

- Simple front-end based on *Leaflet* + *Bootstrap*
- Back-end fetches data from SACM

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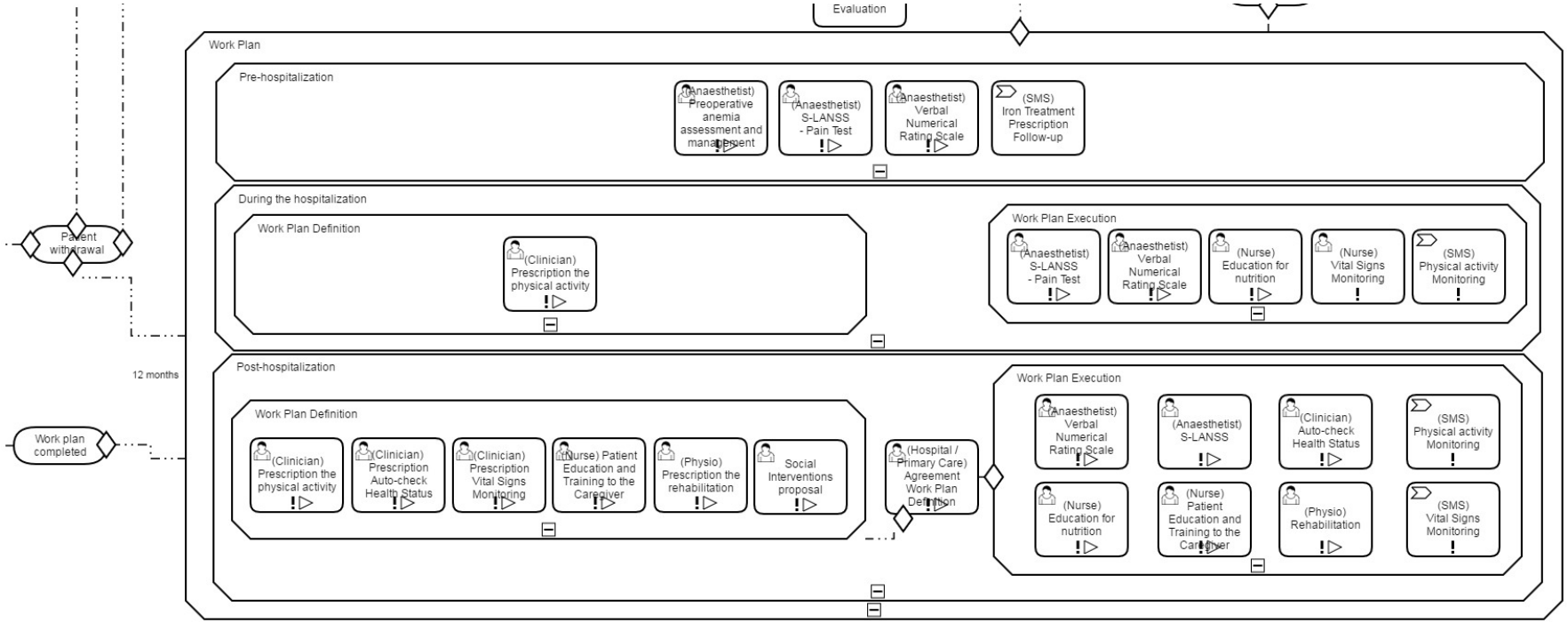
The Clinical Decision Support System

Clinical pathways

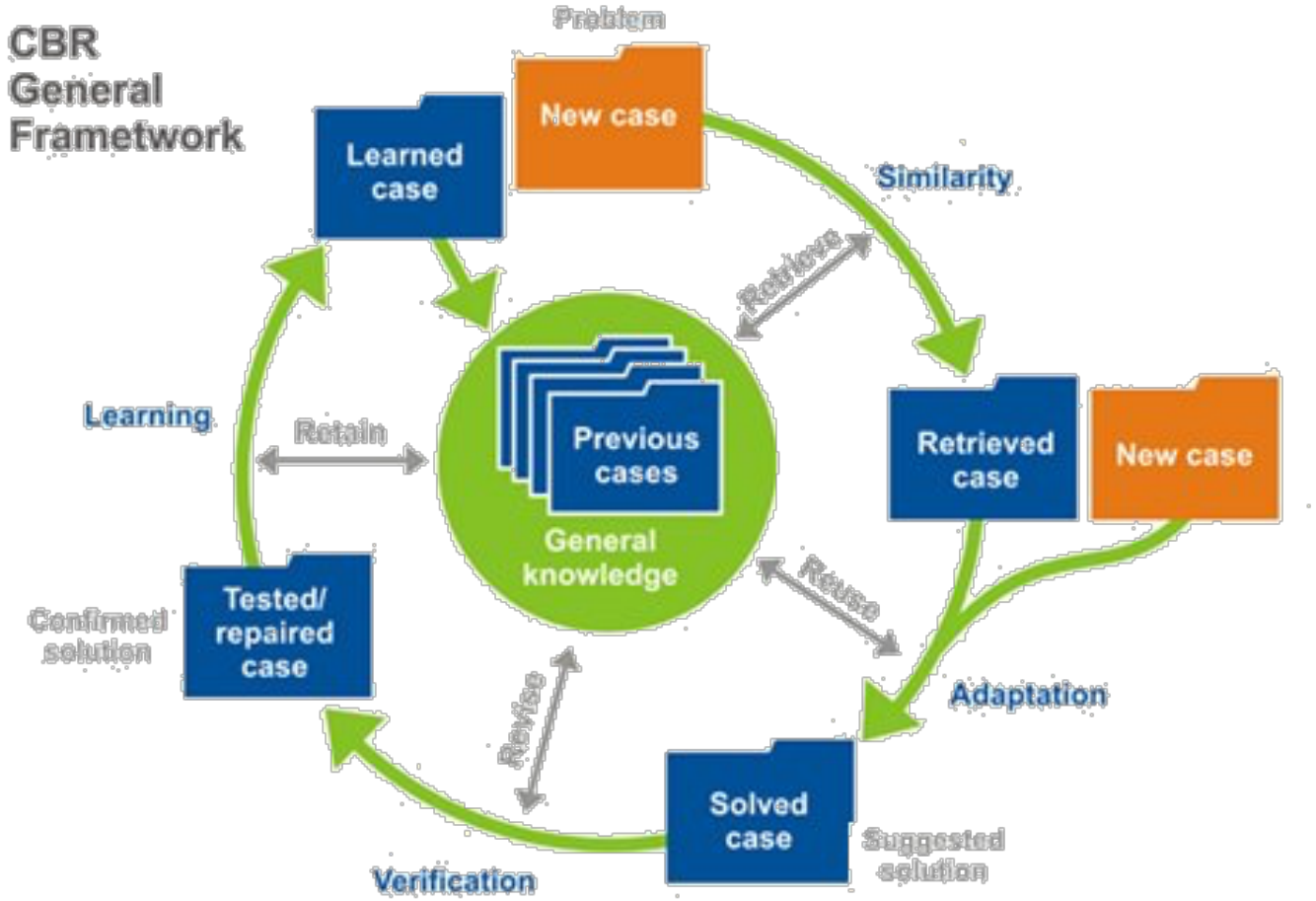
- **Motivations**:
  - paradigm shift towards *predictive* and *personalised* medicine
  - *rule-based* systems for clinical management accepted in clinical practice
  - exploitation of *data analytics* still far from reaching maturity
    - mostly due to ethical and legal issues

- **Goals**:
  - *suggest* treatments, medications, etc. to clinicians based on patient status
    - clinical, cognitive, social, …
  - namely, define the **clinical pathway**
  - *accessibility* from clinicians' workstations
  - *flexibility* of licensing policy and software (re)configuration
  - openness to iterative software improvement

- **Clinical pathway** = *process* composed of *well-standardised* tasks to be carried out on a patient based on health and social condition
  - vs. *industry*: treatment process *varies* for each patient and depends on the *evolving* health state of the patient
    - therefore, needs to be *adapted dynamically*
    - "do W, then if X do Y, unless Z holds" etc. at runtime



- Possible approaches:
  - **Case-based reasoning**
    - *“if in the past X worked for Y, and Z is similar to Y, do X for Z too”*
    - strict *constraints* on software architecture
    - more feasible as a *methodology* to follow
  - **Association rules mining**
    - needs *lots of data*
      - patient clinical status details (each individual symptom, exam, etc.)
      - correspondant therapy (medication, activities, etc.)
      - outcome (impact of a therapy on a status)
    - outputs rules *associating* each therapy to each status, with metadata:
      - likelihood of success
      - confidence/coverage of the rule
  - **Rule-based system**


CBR
General
Frametwork
Problem
New case
Learned case
Similarity
Retrieve
Learning
Retain
Previous cases
General knowledge
Retrieved case
New case
Reuse
Tested/ repaired case
Confirmed solution
Revise
Adaptation
Solved case
Suggested solution
Verification

- **Rule-based system**
  - no need for data
  - but strong collaboration with clinical partners to define rules
    - literature, best practices, etc.
- Rules associating *disease / clinical status / symptom* to *therapy / medication / prescription*
  + rules constraining composition of therapies / medications / prescriptions
    - conflicting medications, therapies, etc.
    - ordering of actions
    - …
  + definition of *admissible* therapies / medications / prescriptions
  + definition of *metrics* to measure success / failure of the above

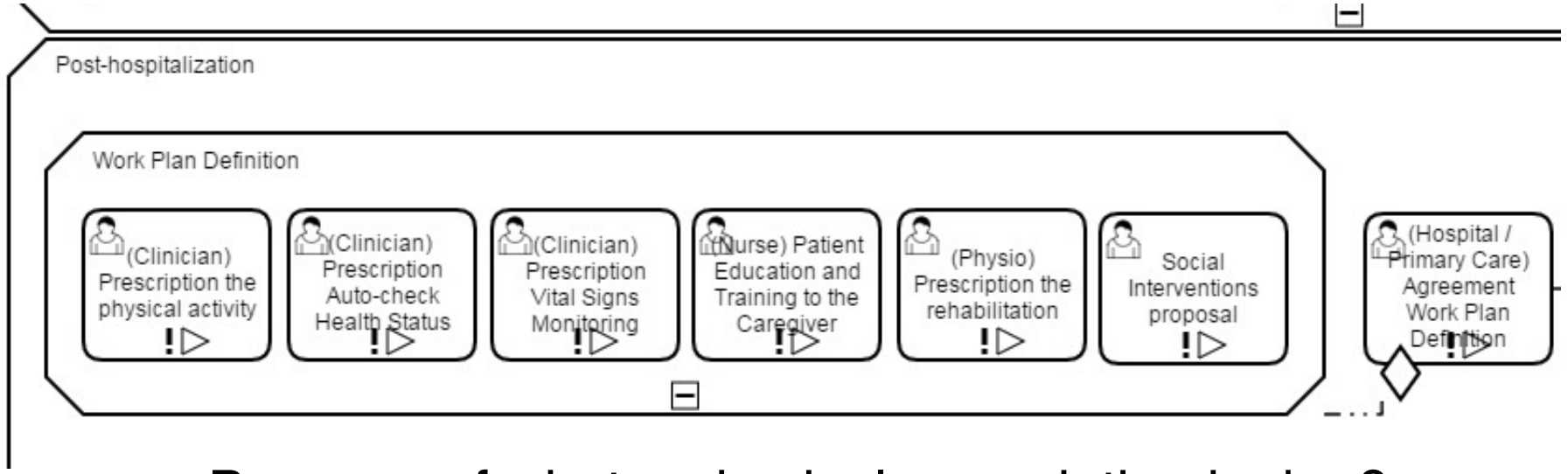
RULE = what?

generally, “when EVENT if CONDITION then ACTION”

in healthcare, = when TASK if DISEASE then PRESCRIPTION **?**

= when STAGE if CONDITION then THERAPY **?**

… **?**



Because of what a physical prescription is due?

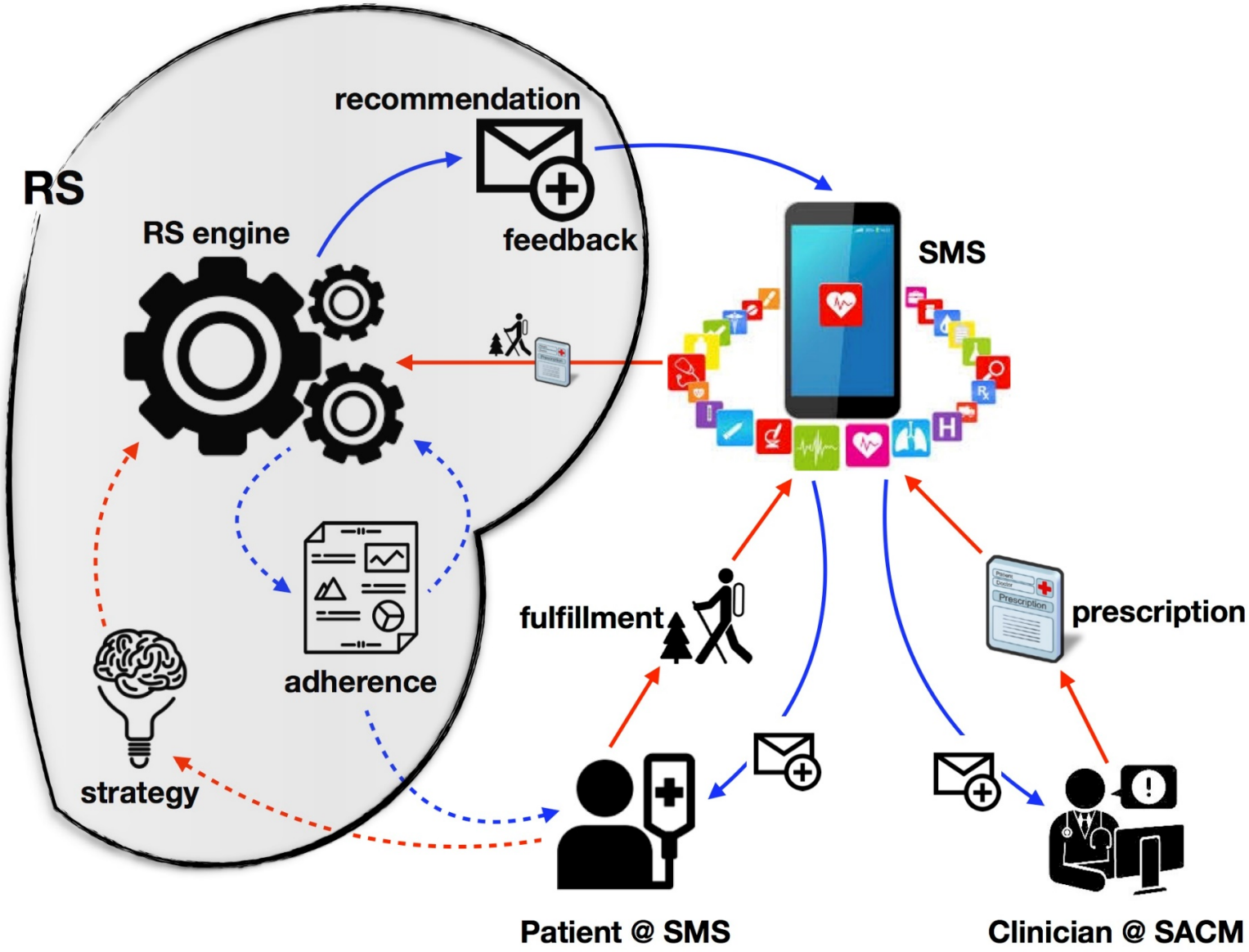
Which health condition triggers vital signs monitoring?

Which factors motivate the need for proposing social interventions?

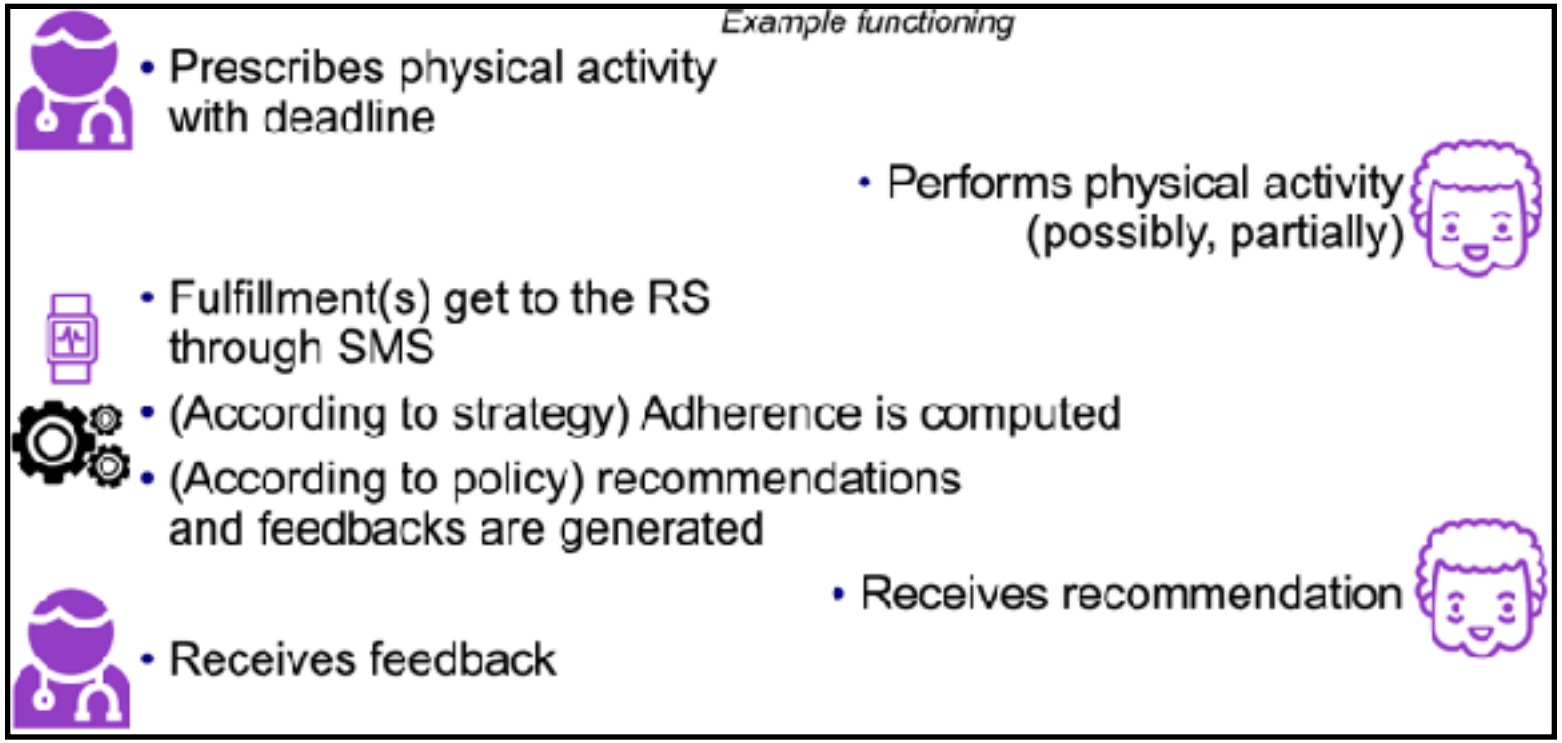
The Recommender System

- **Motivations**:
  - paradigm shift toward *personalised medicine*
  - paradigm shift toward *patient empowerment*
  - patients need constant *engagement* for fullfilling prescriptions
  - clinicians need regular *feedback* on prescriptions

- **Goals**:
  - *motivate* patients to fullfill prescriptions
  - keep clinicians updated on *adherence* of patients to prescriptions
  - promote disease management and relationship with healthcare providers


RS
recommendation
feedback
RS engine
SMS
adherence
strategy
fulfillment
prescription
Prescription
Patient @ SMS
Clinician @ SACM

- **Prescription**: *tasks* assigned to patient by clinician (i.e. physical activity, medications, questionnaires, …)
- **Fulfillment**: (partial) *accomplishment* of a prescription by the patient
- **Adherence**: *compliance* to prescriptions
  - i.e. not compliant, almost compliant, compliant, outstanding



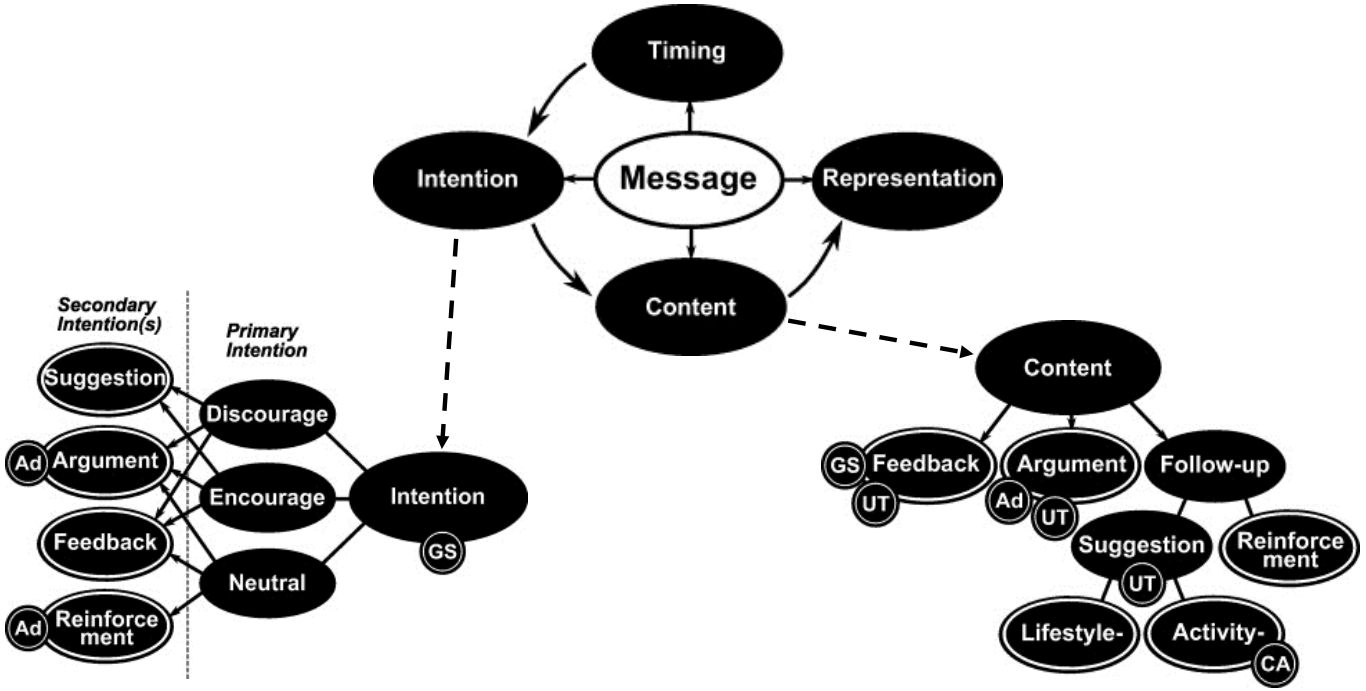
- **Strategy** / **Policy**: criteria guiding *decision making* about
  - *how* to compute the adherence (strategy)
    - i.e. % of activity done w.r.t. prescription goal
  - *which* recommendation / feedback to send (policy)
    1. compute *ideal average* activity (= to get to 100%) per time unit (i.e. daily basis)
    2. *compare* with activity done
    3. <25%, <50%, <75% *thresholds* to generate alert, warning, motivational (award if >=100%) recommendations
  - *when* (policy)
    - i.e. adherence too low or approaching prescription deadline

- **Recommendation**: message *for the patient* as engagement, reward, or warning, depending on adherence
- **Feedback**: message *for the clinician* as follow-up, depending on adherence

Several examples of recommendations:

	Based on event	For patient	For clinician
Based on historical data	The average number of steps improves (last week, month, etc.)	Awards for patient ("Very good!", "Keep it up!")	Feedback: e.g. update prescription
	The average number of steps decreases (last week, month, etc.)	Alert/Motivational message for patient ("Try to do it better!", "Yes you can!")	Alert: compliance gets worse, detect the problem and adjust prescription or motivate the patient.
Based on real-time data	Today's number of steps fulfilled	Awards for patient ("Very good! What a wonderful day!", "Better than yesterday!")	Feedback: punctual compliance
	Today's number of steps not fulfilled	Alert/Motivational message for patient ("You can do it better and you know it!", "Last week you did it better"," It's 18:00 and you've only done 50% of the steps.")	

- **Personalisation**:
  - reasonably well agreed upon *structure* of a generic recommendation message
  - i.e.,"*Tailored motivational message generation: A model and practical framework for real-time physical activity coaching*" (doi: 10.1016/j.jbi.2015.03.005)



- Not so well understood mechanisms for *automatically* generating the messages
- Many different approaches, mostly either **rule-based** or exploiting *machine learning*
- **5 languages** in CONNECARE
  - spanish, catalan, dutch, hebrew, russian

- **Sentence template**:
  - ALERT
    - “Hi *${rec.target}*, is everything alright? Your *${rec.level}* of *${rec.metric}* goal is still far away...time to move! *${rec.expiration}* is approaching :)”
  - WARNING
    - “Hi *${rec.target}*, how is it going? You're almost done with *${rec.metric}*, only *${rec.remaining}* remaining :) Make sure to make it for *${rec.expiration}*!”
  - …
- Things within *${ }* are the *templates* to be substituted at *runtime* for personalization
- Things outside are to be translated, some *manually*, some *automatically*
  - depending on whether they embed some grammar rule or not
  - depending on availability of *Natural Language Generation* libraries
    - i.e. SimpleNLG (https://github.com/simplenlg/simplenlg)

- **Contextualisation**:
  - weather conditions
  - time of the day and day of the week (plus holidays, etc.)
  - patient's mood, habits, preferences, etc.
  - unexpected events (hospitalisations, acute episodes, etc.)
  - …

- What context to consider?
  - weather? —> need GPS consent of patient
  - holydays or calendar events? —> need access to patient calendar
  - personal preference? —> need user profilig consent

Opportunities

- **CDSS**
  - **risk assessment**
    - play with health data using *machine learning*
    - play with *distributed systems* using micro-services
  - **mapping**
    - play with data using *text mining*
    - play with *web apps* using micro-services
    - play with *graph data* using visualisationa and navigation algorithms
  - pathways
    - play with health data using *rule engines*
    - play with health data using *case-based reasoning*
    - play with *distributed systems* using micro-services
- **Recommender**
  - play with text content using *natural language generation*
  - play with non-health data using *context recognition algorithms*
  - play with *distributed systems* using micro-services

Thanks
Bedankt תודה Gràcies
Grazie Danke

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