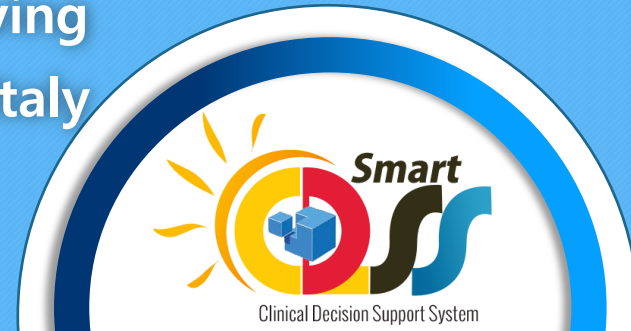


Connected Health Summer School

Smart Environments for Smarter Living
27-30th June 2016 - Artimino, Firenze, Italy



SmartCDSS and Authoring Tool

June 28th 2016

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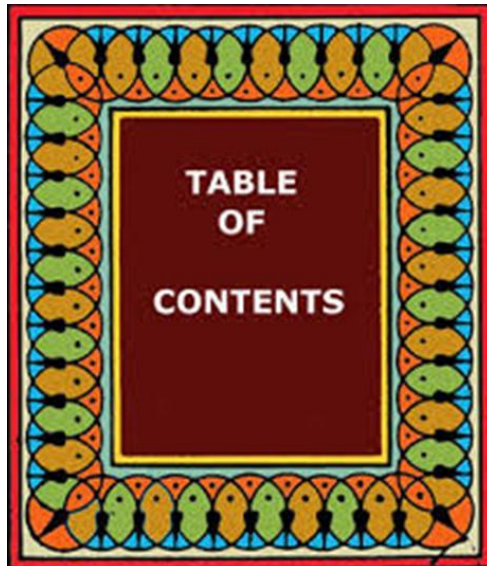
<http://udab.khu.ac.kr>



경희대학교
KYUNG HEE UNIVERSITY

UCL Ubiquitous Computing Laboratory
Kyung Hee University, Korea

SmartCDSS and Authoring Tool



I . Introduction to Clinical Decision Support System (CDSS)

II . Proposed Smart CDSS

- II-1 Three Phase Knowledge Acquisition Model
- II-2 Knowledge Authoring Tool
- II-3 Evidence Support
- II-4 Execution Engine

III . Summary

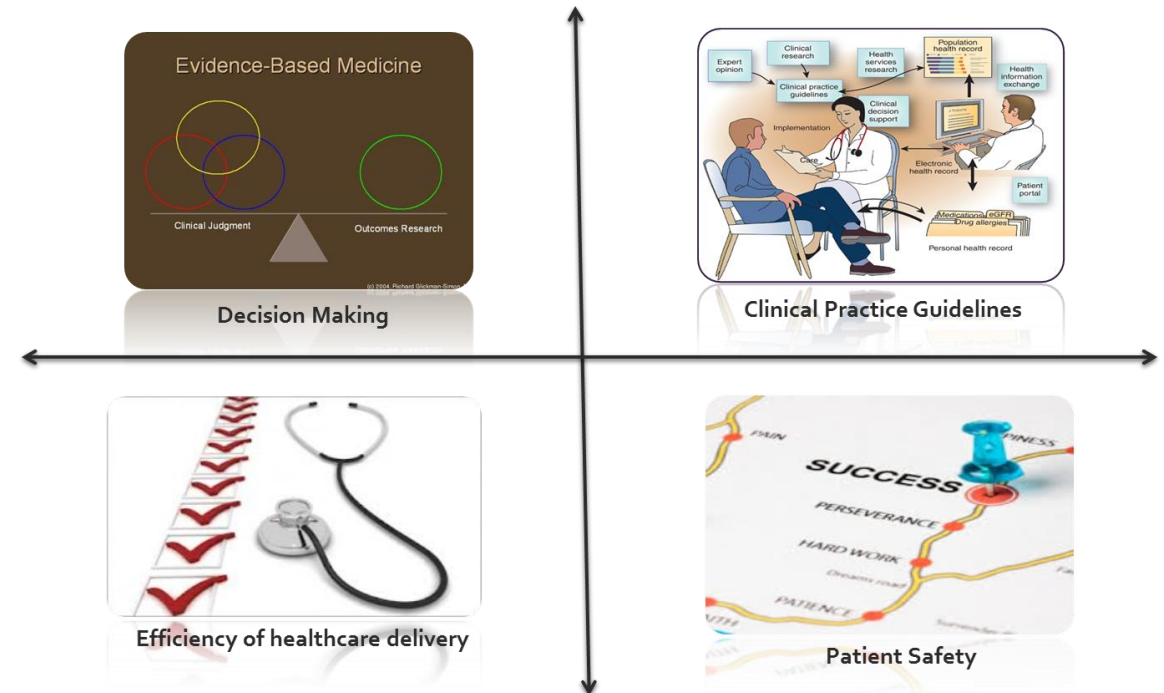


Watson Products and Infrastructure



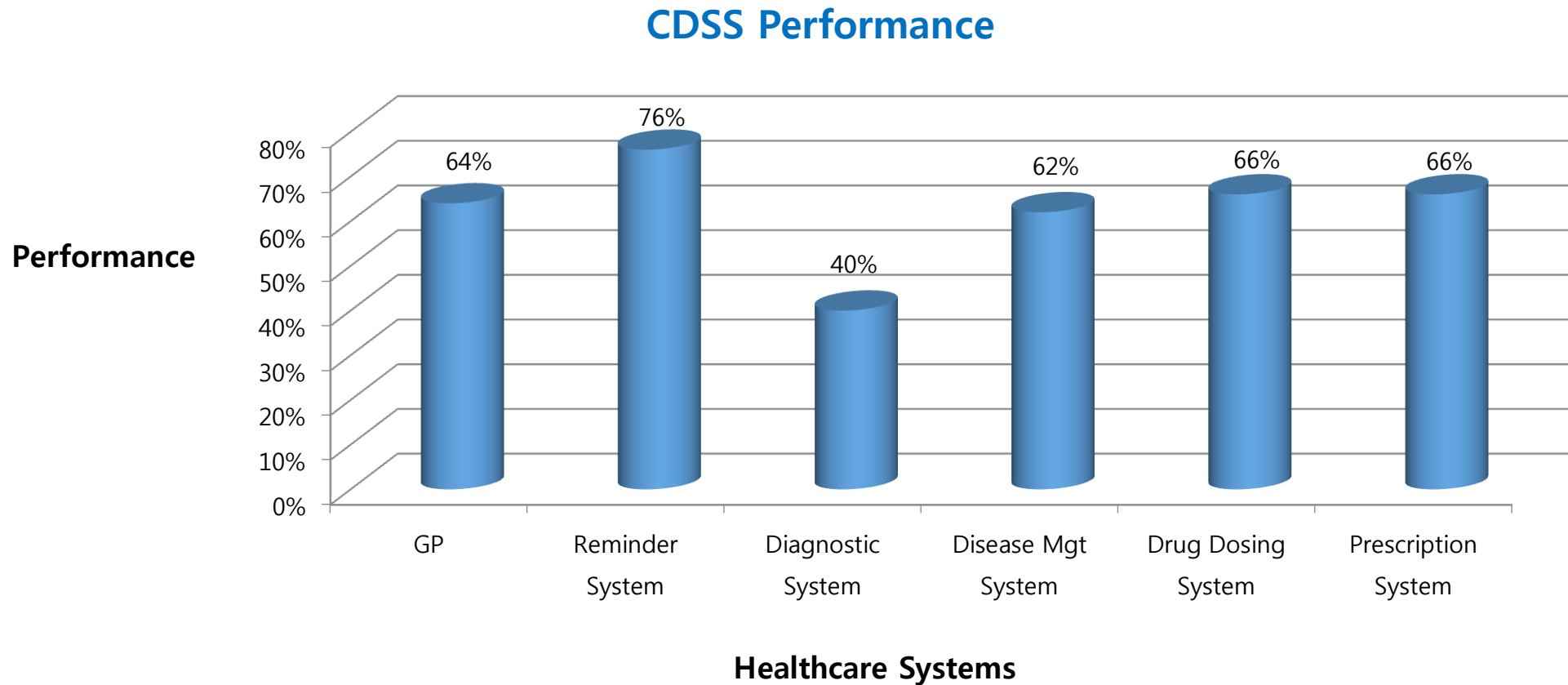
What is CDSS?

- CDSS is a tool that helps in making better medical decision thereby reducing clinical errors and improves quality of care.
- CDSS has potential applications in area of;
 - ✓ Generating alerts and reminders
 - ✓ Diagnostic assistance
 - ✓ Therapy critiquing and planning
 - ✓ Image recognition and interpretation



Source: Wilfred Bonney, Capella University/HL7 International, Canada: Impacts and Risks of Adopting Clinical Decision Support Systems, Chapter 2.

CDSS Performance in various domain



Source: Dereck L. Hunt., et al. "Effects of computer-based clinical decision support systems on physician performance and patient outcomes: a systematic review" *Jama* 280. 15 (1998): 1339-1346.



Credible



Secure



Personalized



Reliable



Accurate



Transparent



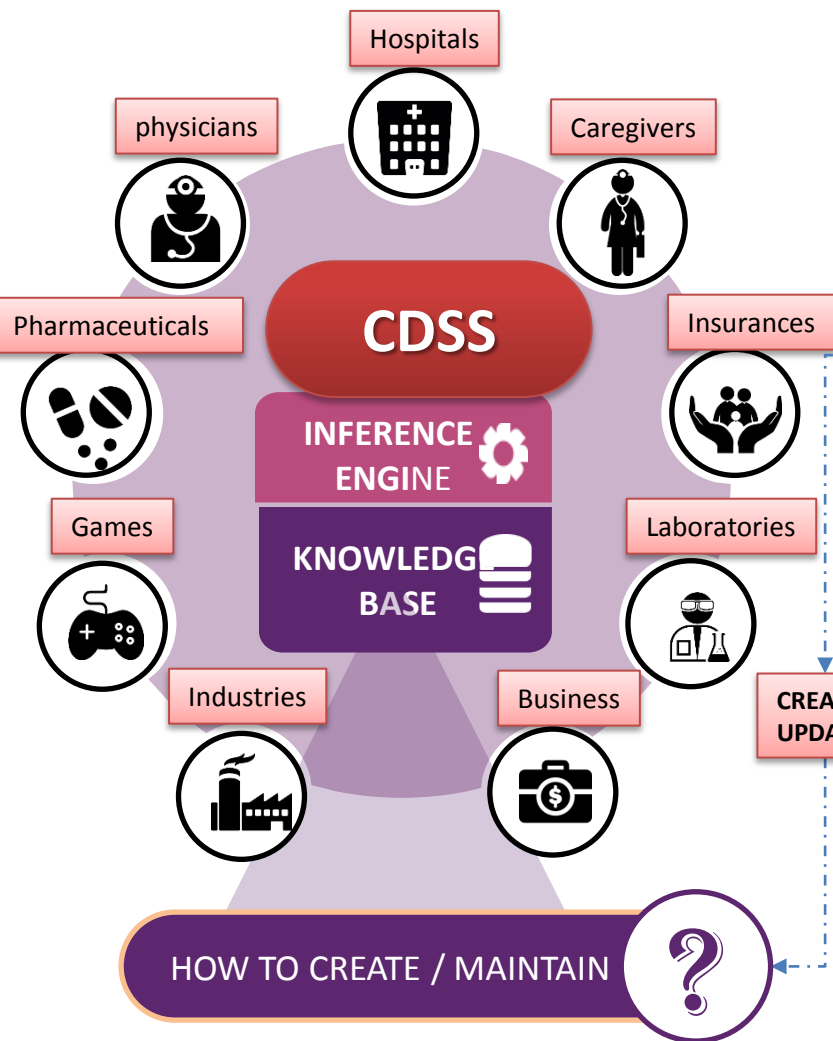
Context Aware



Easy to use

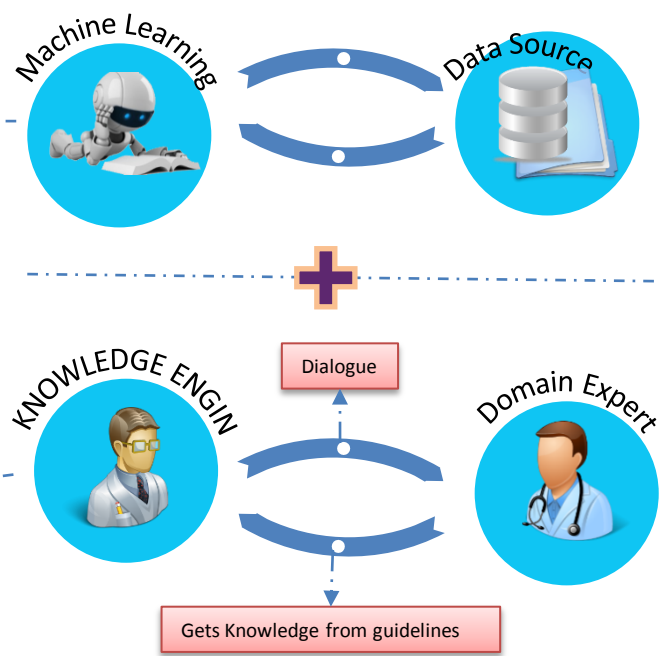


- **Knowledge Representations**
 - Arden Syntax , XML, Ontological Representation, RDB
- **Knowledge (Rules) Type**
 - MLM (Medical Logic Module) vs Plain Rule (Production rule)
- **Knowledge Acquisition & Quality**
 - Data Driven, Expert Driven, or Hybrid
 - Integrity, Accuracy, interoperability, Shareability, Up-to-date
- **Knowledge Validation & Verification**
 - Model level, Execution level, or both
 - RDR (Ripple Down Rule), CBR (MLM Augmented CBR)
- **Authoring Tool Support**
 - Interface for Knowledge Maintenance
 - UI/UX, Analytics, Visualization
- **Evidence Support**
 - Query and Quality for PubMed
- **Interoperability**
 - Process interoperability and Data interoperability
 - Standardization (HL7, FHIR)



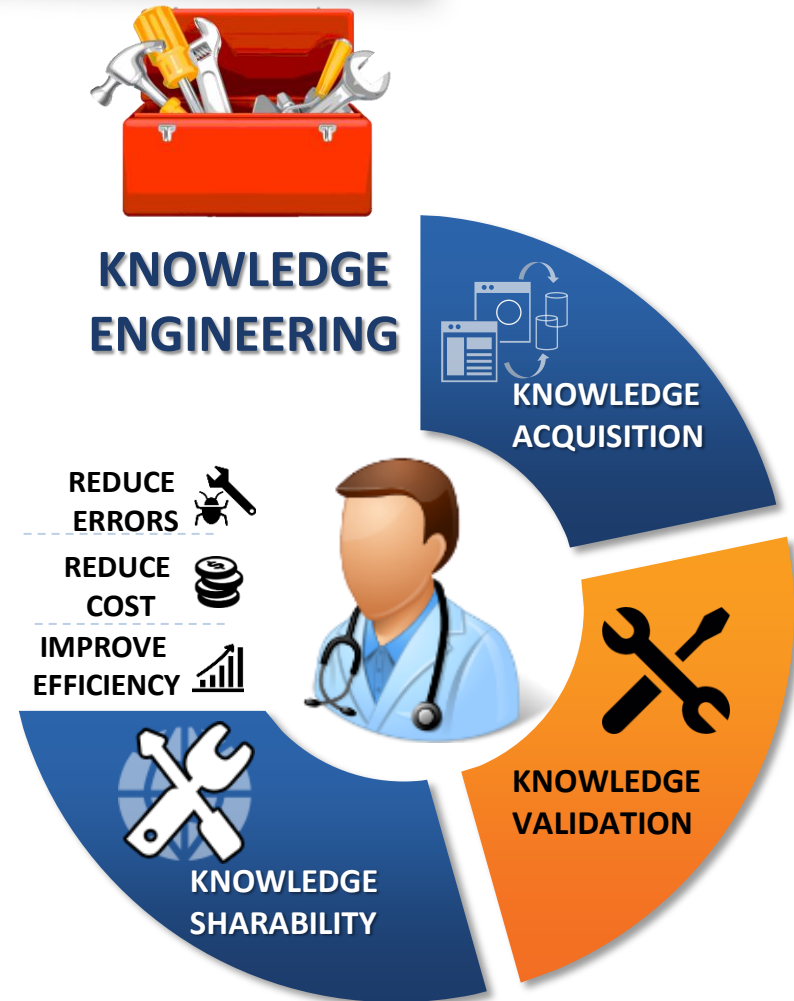
Limitations (Data Driven)

- Accuracy Issue
- Knowledge Validation
- Evidence is missing (from standard guidelines)



Limitations (Expert Driven)

- Highly dependency on Knowledge Engineer (KE)
- Difficult to validate knowledge by KE



Plain Rule

PROS

CONS

Natural knowledge representation +

Easy to understand +

Explicit separation between knowledge and processing +

Supporting incomplete and uncertain knowledge +

Uniform structure +

Plain Rule

No shareability -

No relations between rules -

Less expressive -

No evidence support -

Ineffective search strategy -

Not Turing complete system -

No uniform implementation -

No mechanism for handling meta information -

VS

Medical Logic Module

PROS

CONS

Standard Representation +

Shareable knowledge +

Evidence support +

Highly expressive +

Meta information handling +

Clinician centric representation +

Explicit knowledge specification +

Medical Logic Module MLM

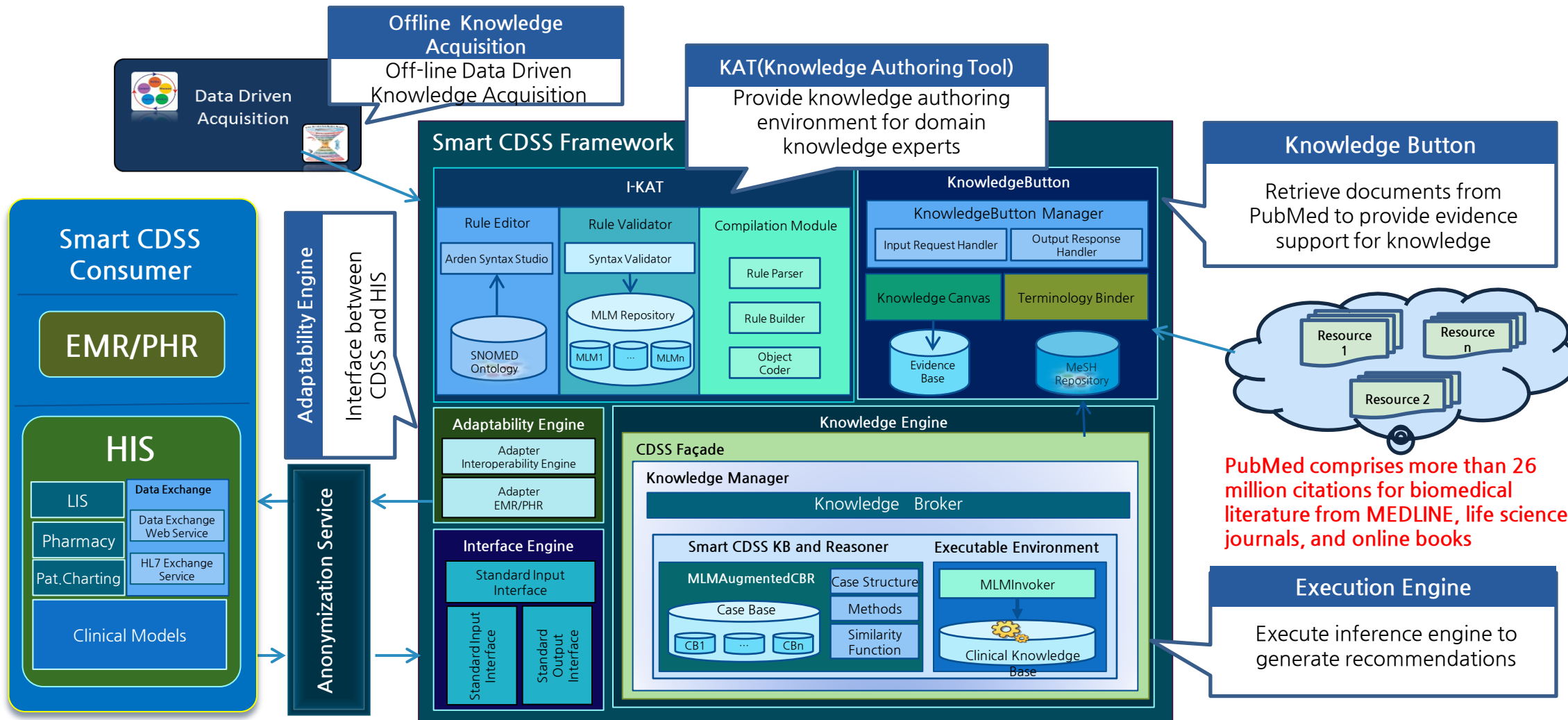
Complex implementation -

Integration Problem with HIS -

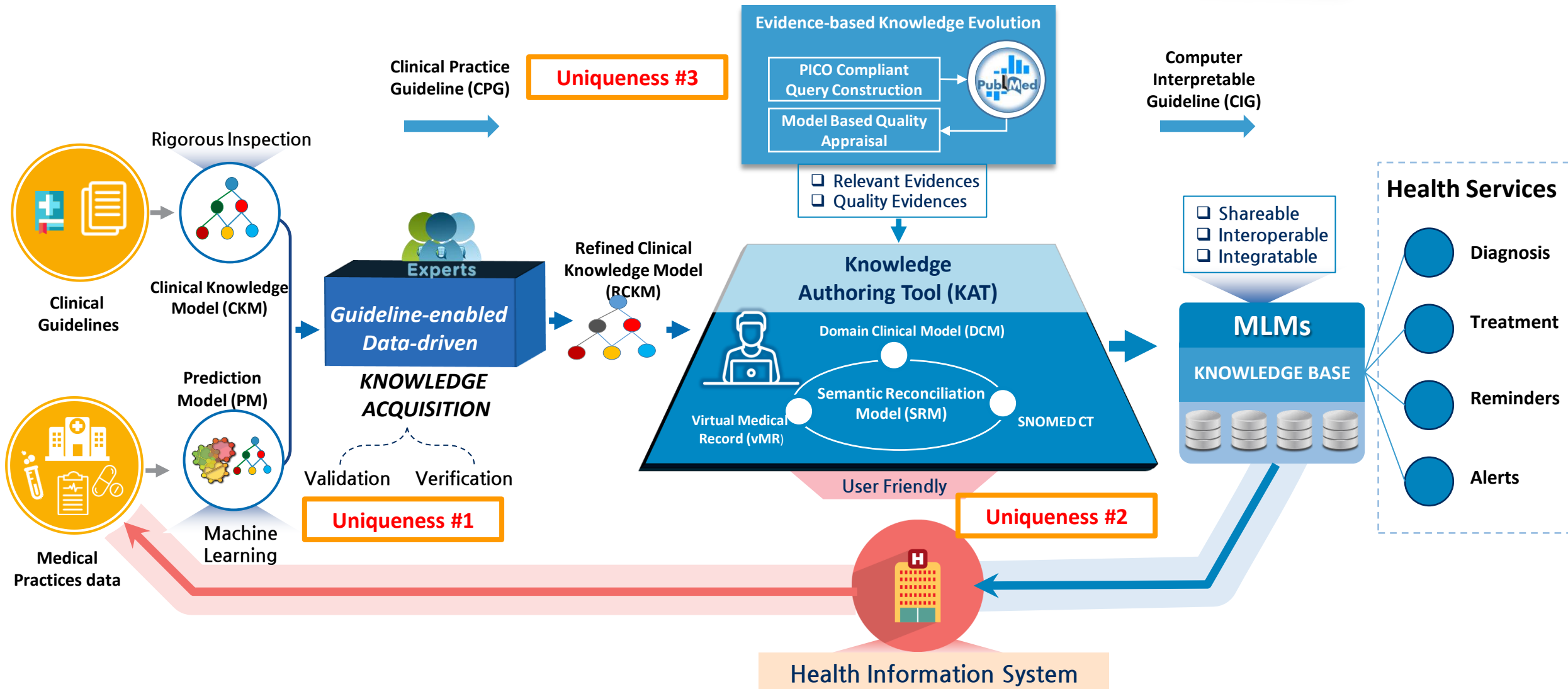
Transformation to executable code -

MLM is hybrid between production (plain) rule and programming language

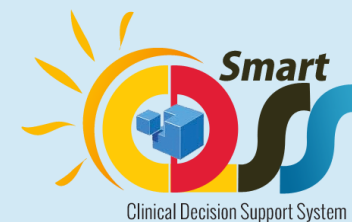
Smart CDSS Architecture



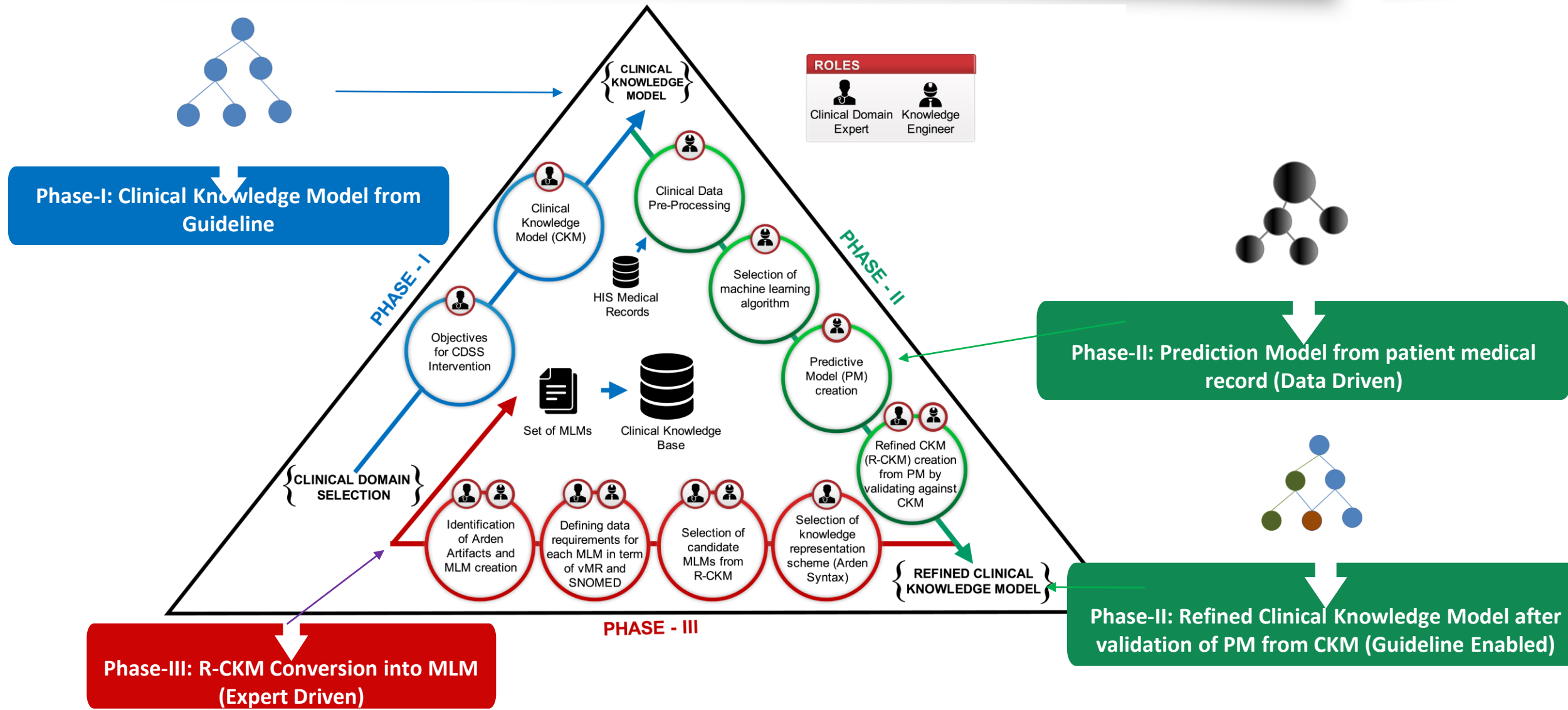
Major Contributions of SmartCDSS



Knowledge Acquisition



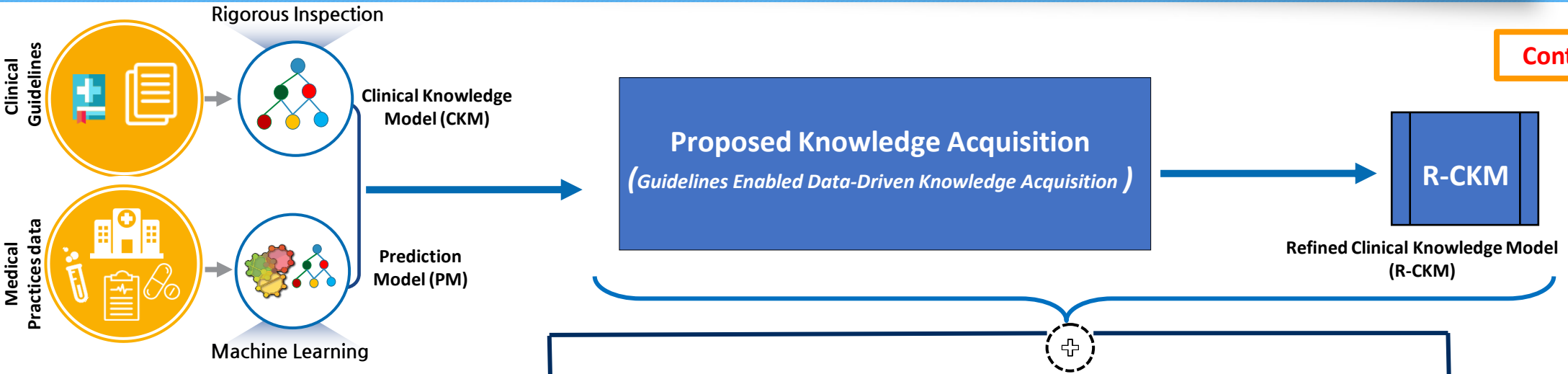
3 Phase Knowledge Acquisition Model



Summary of Data-Driven Knowledge Acquisition

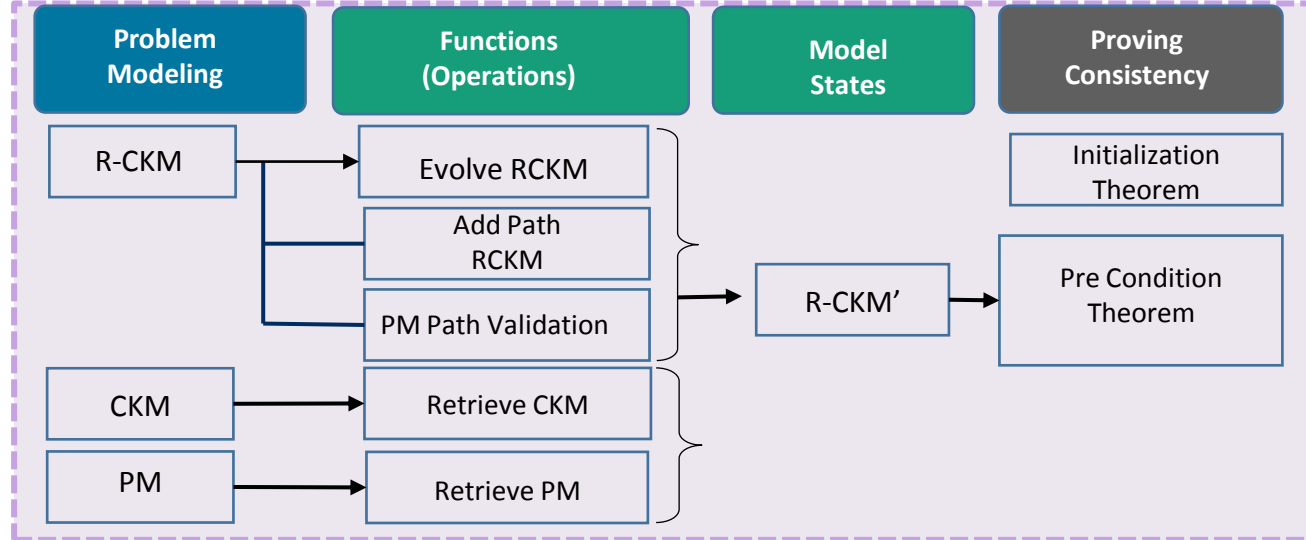
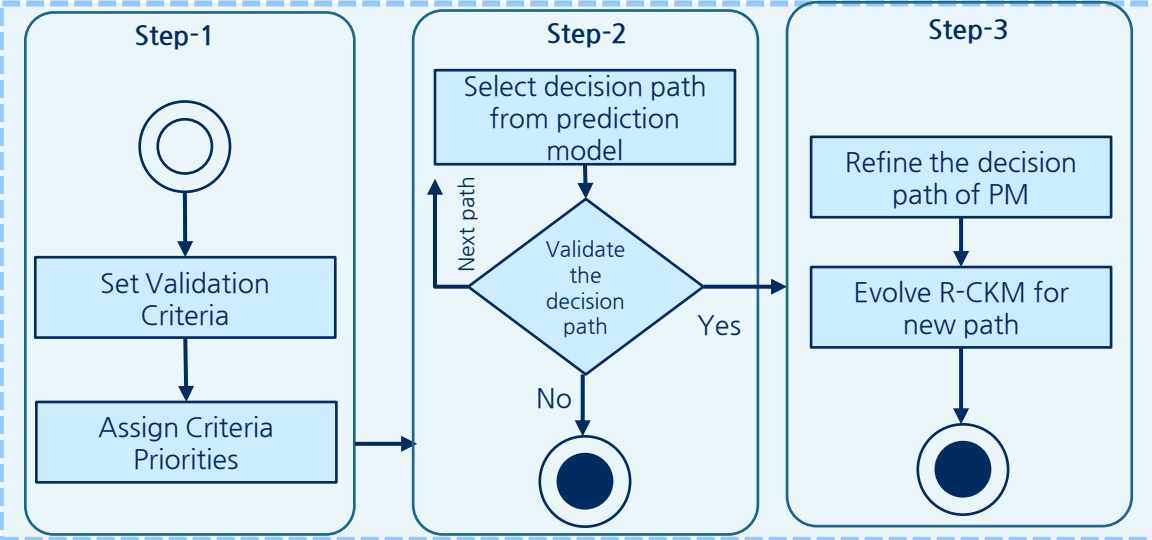


Contribution #1

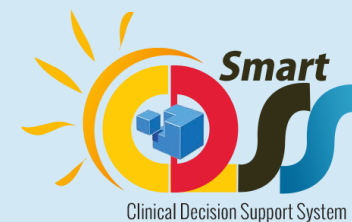


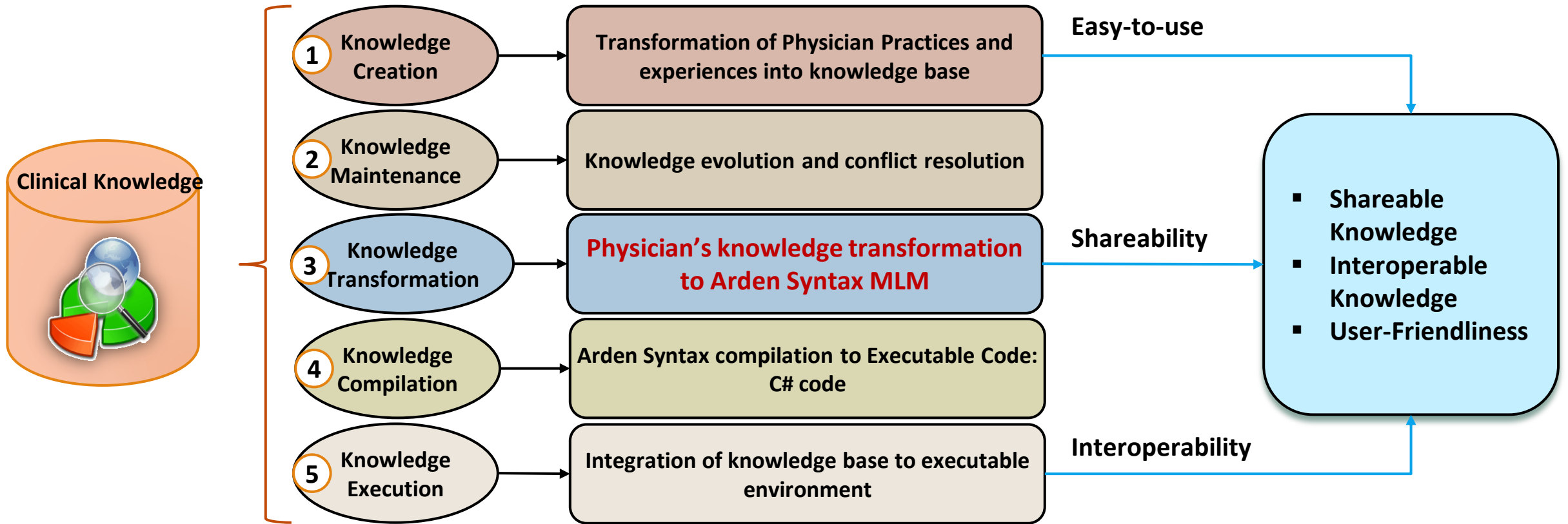
Validation

Verification

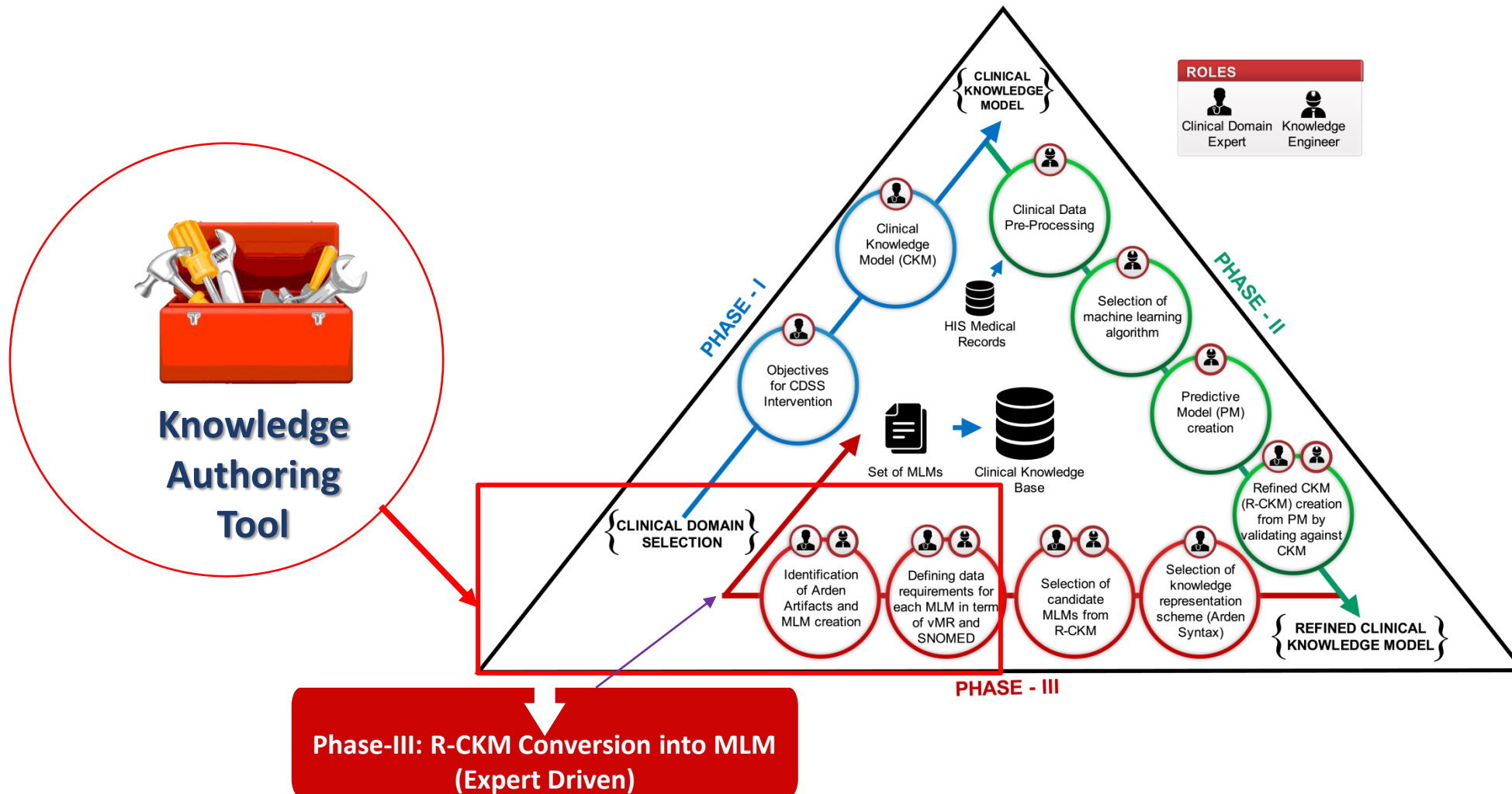


Knowledge Authoring Tool





Expert Driven Knowledge Acquisition with KAT

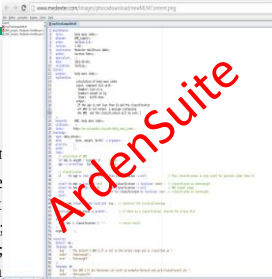


if Treatment Intent is palliative then radiotherapy is recommended as treatment plan.

Plain Rule

maintenance:

```
title: Palliative Treatr
mlmname: Palliative
arden: Arden Syntax
version: Version 2.7;;
institution: SKMCH;
author: Dr. Physician
specialist: Dr. Physician 3;;
date: 13/01/2015;;
validation: testing;;
```



ArdenSuite

- Standard MLM
- Not Shareable
- Not Interoperable
- Complex

Library:

```
purpose: Experimental testing;;
explanation: Experimental testing;;
keywords: Oral Cavity;;
citations: ;;
```

Knowledge:

```
type: data driven; ;
data:
LET varTreatmentIntent = BE Read { Select TreatmentInten from ClientDB }
;;
```

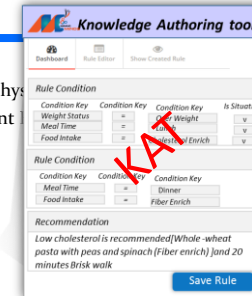
evoke: null_event;;

```
logic:
if ( varTreatmentIntent is equal to Palliative)
{
Conclude true;
};
action:
WRITE "The recommended treatment plan is Radiotherapy"
at stdout dest; ;;
```

end;

maintenance:

```
title: Palliative Treatment By Phys
mlmname: Palliative Treatment
arden: Arden Syntax V2.7;;
version: Version 2.7;;
institution: SKMCH;;
author: Dr. Physician 3;;
specialist: Dr. Physician 3;;
date: 13/01/2015;;
validation: testing;;
```



KAT

Library:

```
purpose: Experimental testing;;
explanation: Experimental testing;;
keywords: Oral Cavity;;
citations: ;;
```

Knowledge:

```
type: data driven; ;
data: ProcedureEvents := object [ProcedureEvent];
ProcedureEventList := read as ProcedureEvents
{ select ProcedureEvent FROM client Where ProcedureEvent.procedureCode IN ("395077000");
Recommendation1 := object [ProcedureEvent];
RecommendationList := () ;;
```

SNOMED CT vMR

evoke: null_event;;

```
logic:
ProcedureEventListDetail := EXTRACT ATTRIBUTE NAMES ProcedureEventList;
ProcedureEvent1 := ATTRIBUTE ProcedureEventListDetail[1] FROM ProcedureEventList;
IF( (ProcedureEvent1.procedureCode = "395077000" And ProcedureEvent1.procedureMethod = "363676003"))
THEN
recPart1 := new ProcedureEvent with "108290001";
rec1 := new Recommendation1 with recPart1;
recommendationList := recommendationList, rec1;
action:
WRITE recommendations.procedureMethod;;
at stdout dest; ;;
```



end;

Advantages of KAT over ArdenSuite



Plain Rule if Treatment Intent is palliative then radiotherapy is recommended as treatment plan.

ArdenSuite

```
11 library:
12   purpose: Experimental testing::
13   explanation: Experimental testing::
14   keywords: Oral Cavity::
15   citations: ::
16   links: ::
17 knowledge:
18   type: data-driven ::
19   data:
20     LET varTreatmentIntent = BE Read { Select TreatmentInten from ClientDB }
21     ;;
22   priority: High ::
23   evoke: user-evolve ::
24   logic:
25     if ( varTreatmentIntent is equal to Palliative )
26     {
27       Conclude true;
28     }
29     Else
30     {
31       Conclude false;
32     }
33   ;;
34   action: ::
35     Write "The recommended treatment plan is Radiotherapy"
36 resources:
37   default: ::
38   language: ::
39 end:
40
41
```

Data (lines 19-21): LET varTreatmentIntent = BE Read { Select TreatmentInten from ClientDB }

Logic (lines 24-33): if (varTreatmentIntent is equal to Palliative) { Conclude true; } Else { Conclude false; }

Action (lines 34-35): Write "The recommended treatment plan is Radiotherapy"

- ❖ Rate of syntax errors in KAT is less than ArdenSuite
- ❖ Expert's performance of KAT is higher than ArdenSuite
- ❖ ArdenSuite requires more efforts of experts to remind syntax and structure of MLM



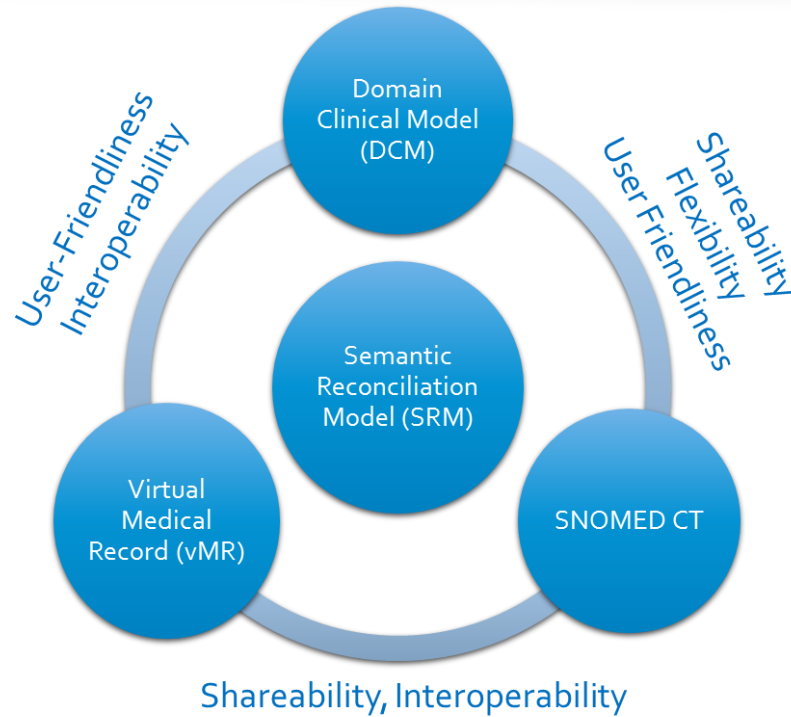
KAT Intelligent Knowledge Authoring Tool

Author's Name: Dr. Physician 3
Institution: SKMCH
Created Date: 13/01/2015
Purpose: Experimental testing
Explanation: Experimental testing

Logic (IF Condition): Treatment Intent = Palliative

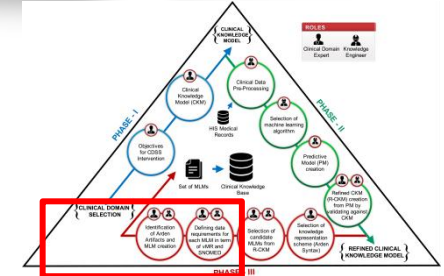
Action (THEN Action): Treatment Plan = Radiotherapy

Recommendation: Low cholesterol is recommended(Whole-wheat pasta with peas and spinach (fiber enrich) and 20 minutes brisk walk)

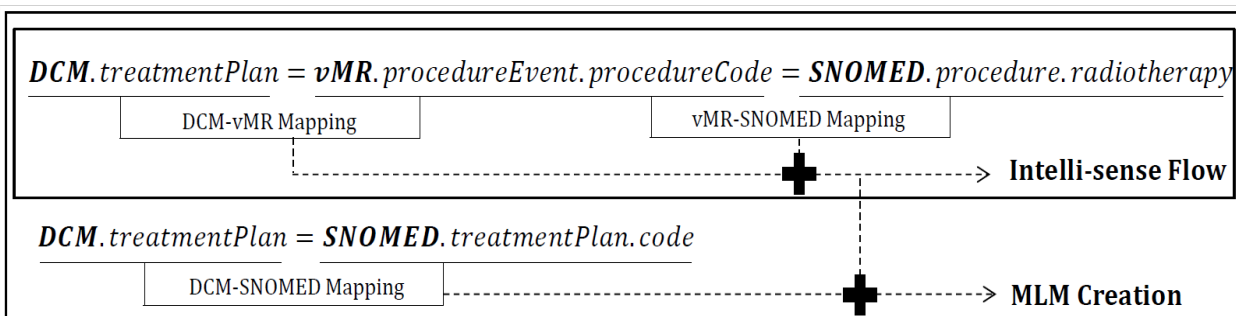


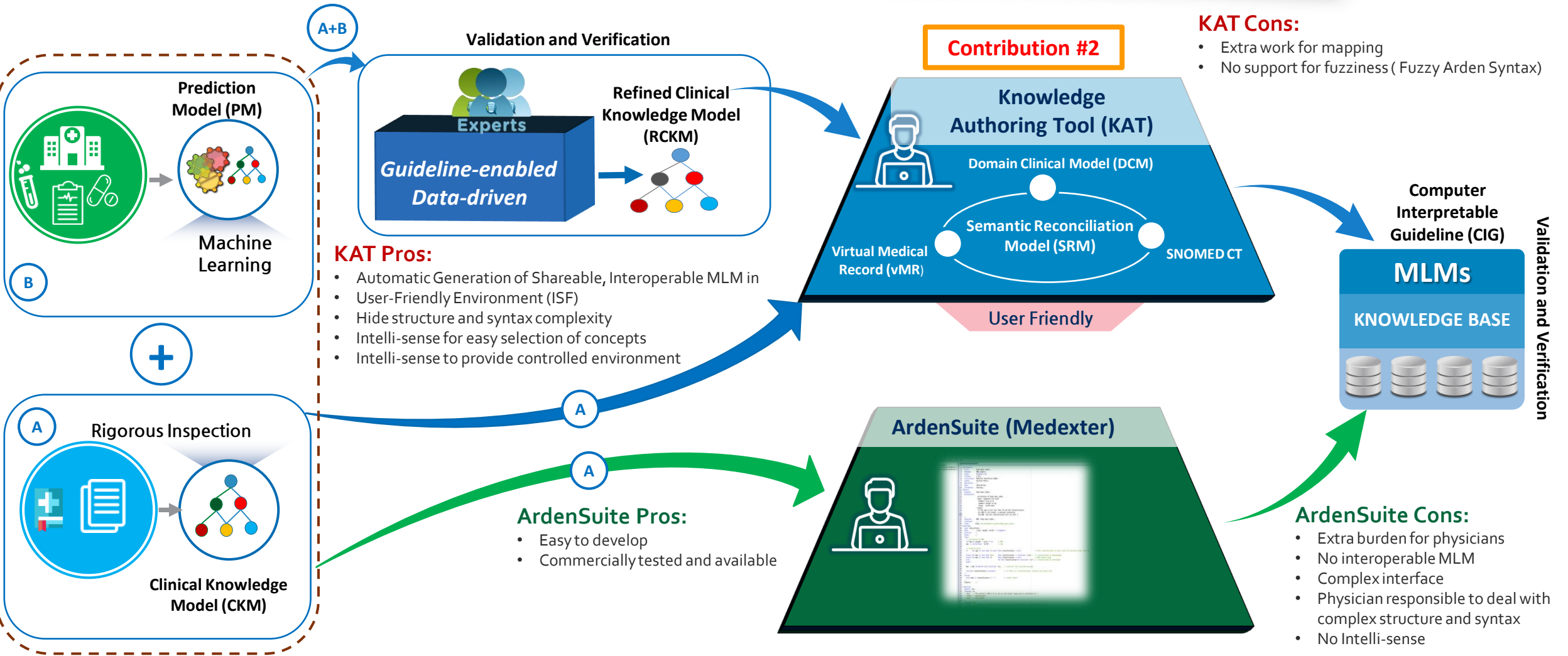
Why SRM?

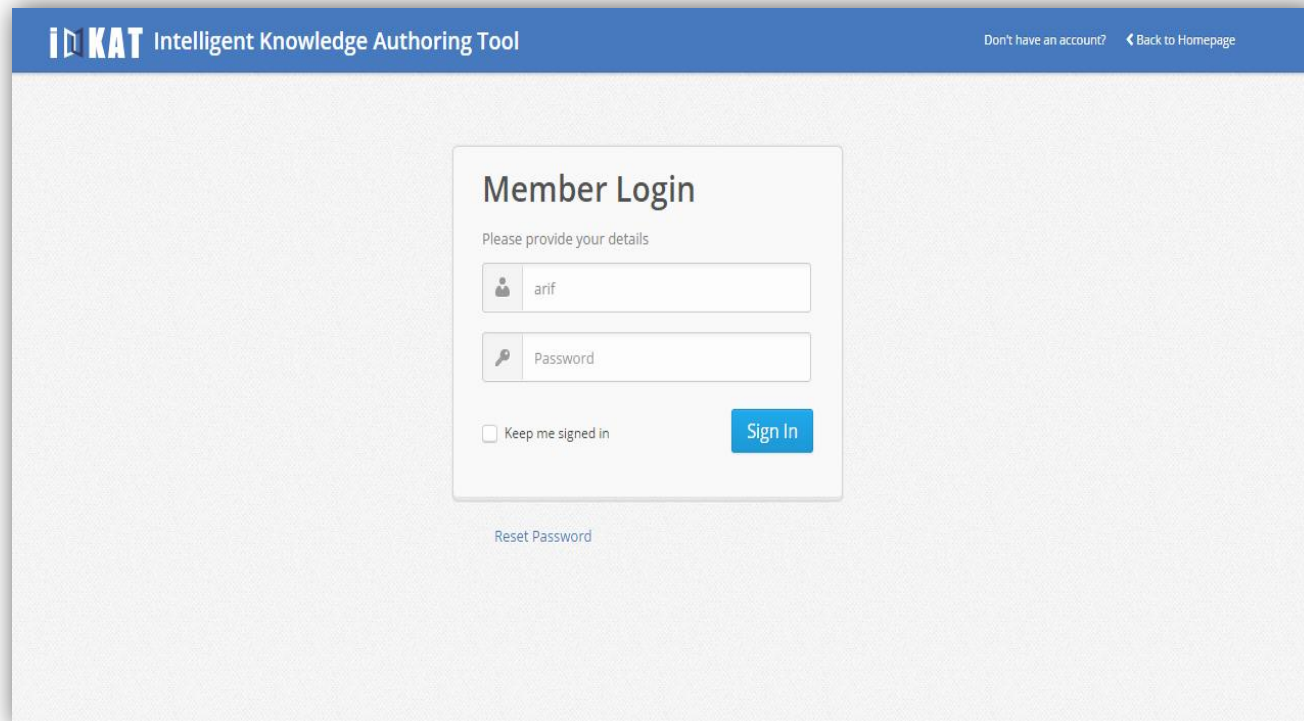
• SRM provides standard data model for final CIG, which is build from three different data models; to achieve following benefits.



- **DCM to SNOMED Mapping**
 - It is mapping between clinical concepts of HMIS systems and SNOMED CT.
 - It enhances the shareability, flexibility, and user friendliness
- **DCM to vMR Mapping**
 - It provides mappings between clinical concepts of HMIS systems and vMR schema classes.
 - It increase user friendliness and Interoperability
- **SNOMED to vMR**
 - It is mapping between the concepts of SNOMED CT and vMR schema classes.
 - It is useable for shareability, and Interoperability

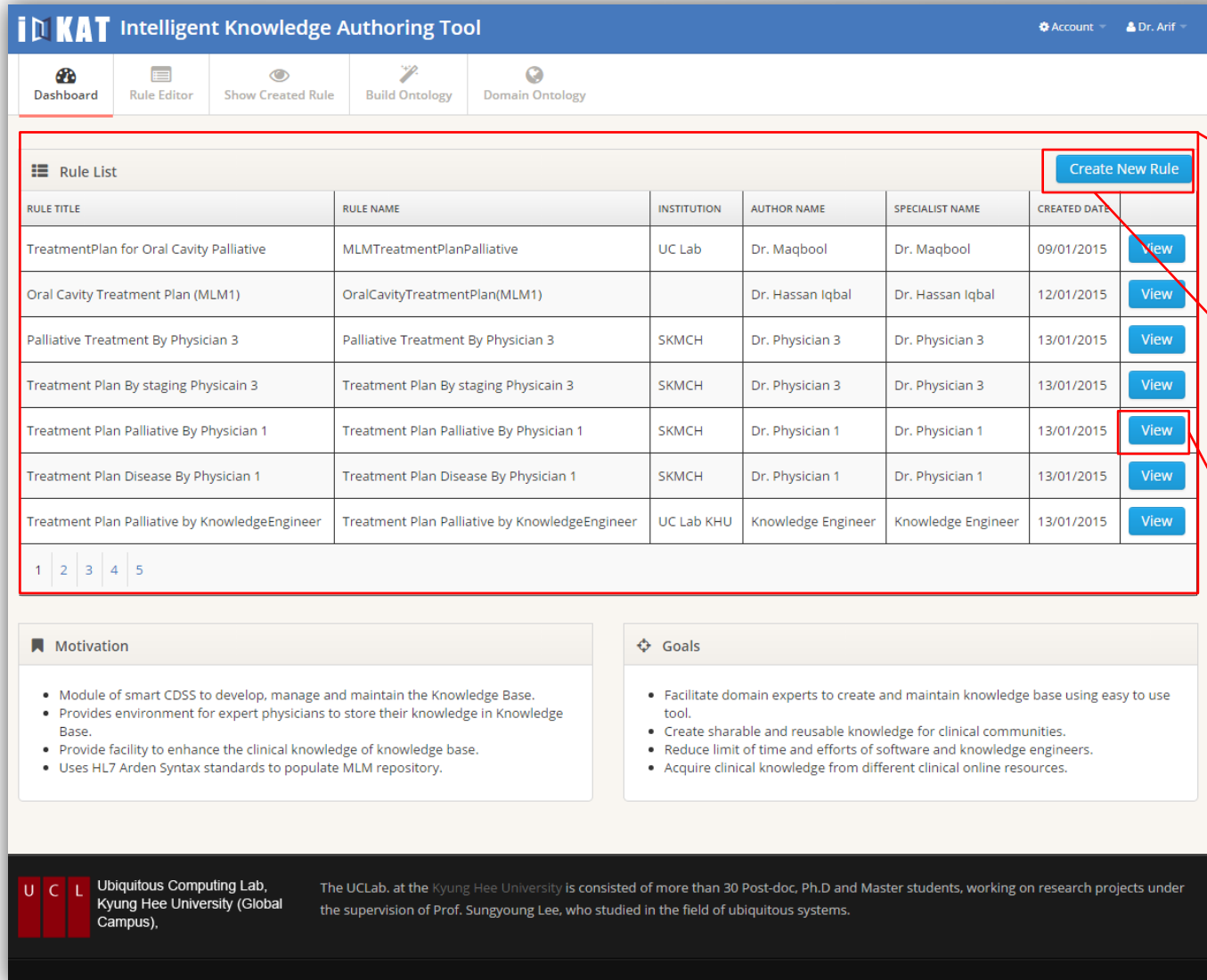






The screenshot shows the 'Member Login' interface for the 'iKAT Intelligent Knowledge Authoring Tool'. The page has a blue header with the logo and navigation links. The main content area is light gray and contains a white login box. Inside the box, there are two input fields: one for the username 'arif' and one for the password. Below the password field is a checkbox for 'Keep me signed in' and a blue 'Sign In' button. A 'Reset Password' link is located below the login box.

- **Authentication:** I-KAT provides user login screen to authenticate domain experts.
- Domain experts can see the screens based on his/her role.
 - Enter user name
 - Enter password



The screenshot shows the I-KAT Intelligent Knowledge Authoring Tool interface. At the top, there is a navigation bar with the tool name and user information. Below it is a menu with options: Dashboard, Rule Editor, Show Created Rule, Build Ontology, and Domain Ontology. The main content area features a 'Rule List' table with columns for Rule Title, Rule Name, Institution, Author Name, Specialist Name, and Created Date. A 'Create New Rule' button is located at the top right of the table. Below the table are sections for 'Motivation' and 'Goals'.

RULE TITLE	RULE NAME	INSTITUTION	AUTHOR NAME	SPECIALIST NAME	CREATED DATE	
TreatmentPlan for Oral Cavity Palliative	MLMTreatmentPlanPalliative	UC Lab	Dr. Maqbool	Dr. Maqbool	09/01/2015	View
Oral Cavity Treatment Plan (MLM1)	OralCavityTreatmentPlan(MLM1)		Dr. Hassan Iqbal	Dr. Hassan Iqbal	12/01/2015	View
Palliative Treatment By Physician 3	Palliative Treatment By Physician 3	SKMCH	Dr. Physician 3	Dr. Physician 3	13/01/2015	View
Treatment Plan By staging Physicain 3	Treatment Plan By staging Physicain 3	SKMCH	Dr. Physician 3	Dr. Physician 3	13/01/2015	View
Treatment Plan Palliative By Physician 1	Treatment Plan Palliative By Physician 1	SKMCH	Dr. Physician 1	Dr. Physician 1	13/01/2015	View
Treatment Plan Disease By Physician 1	Treatment Plan Disease By Physician 1	SKMCH	Dr. Physician 1	Dr. Physician 1	13/01/2015	View
Treatment Plan Palliative by KnowledgeEngineer	Treatment Plan Palliative by KnowledgeEngineer	UC Lab KHU	Knowledge Engineer	Knowledge Engineer	13/01/2015	View

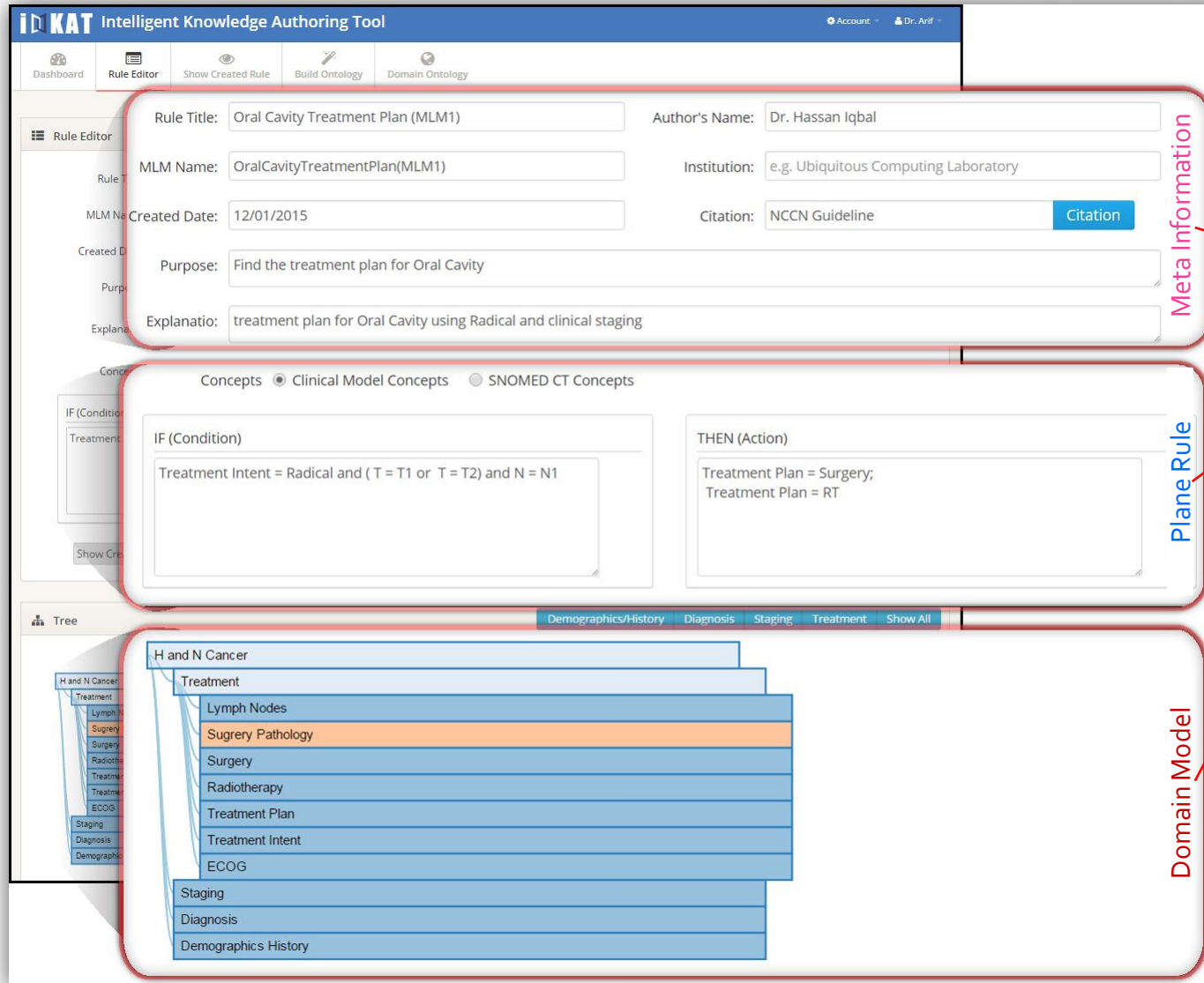
Motivation

- Module of smart CDSS to develop, manage and maintain the Knowledge Base.
- Provides environment for expert physicians to store their knowledge in Knowledge Base.
- Provide facility to enhance the clinical knowledge of knowledge base.
- Uses HL7 Arden Syntax standards to populate MLM repository.

Goals

- Facilitate domain experts to create and maintain knowledge base using easy to use tool.
- Create sharable and reusable knowledge for clinical communities.
- Reduce limit of time and efforts of software and knowledge engineers.
- Acquire clinical knowledge from different clinical online resources.

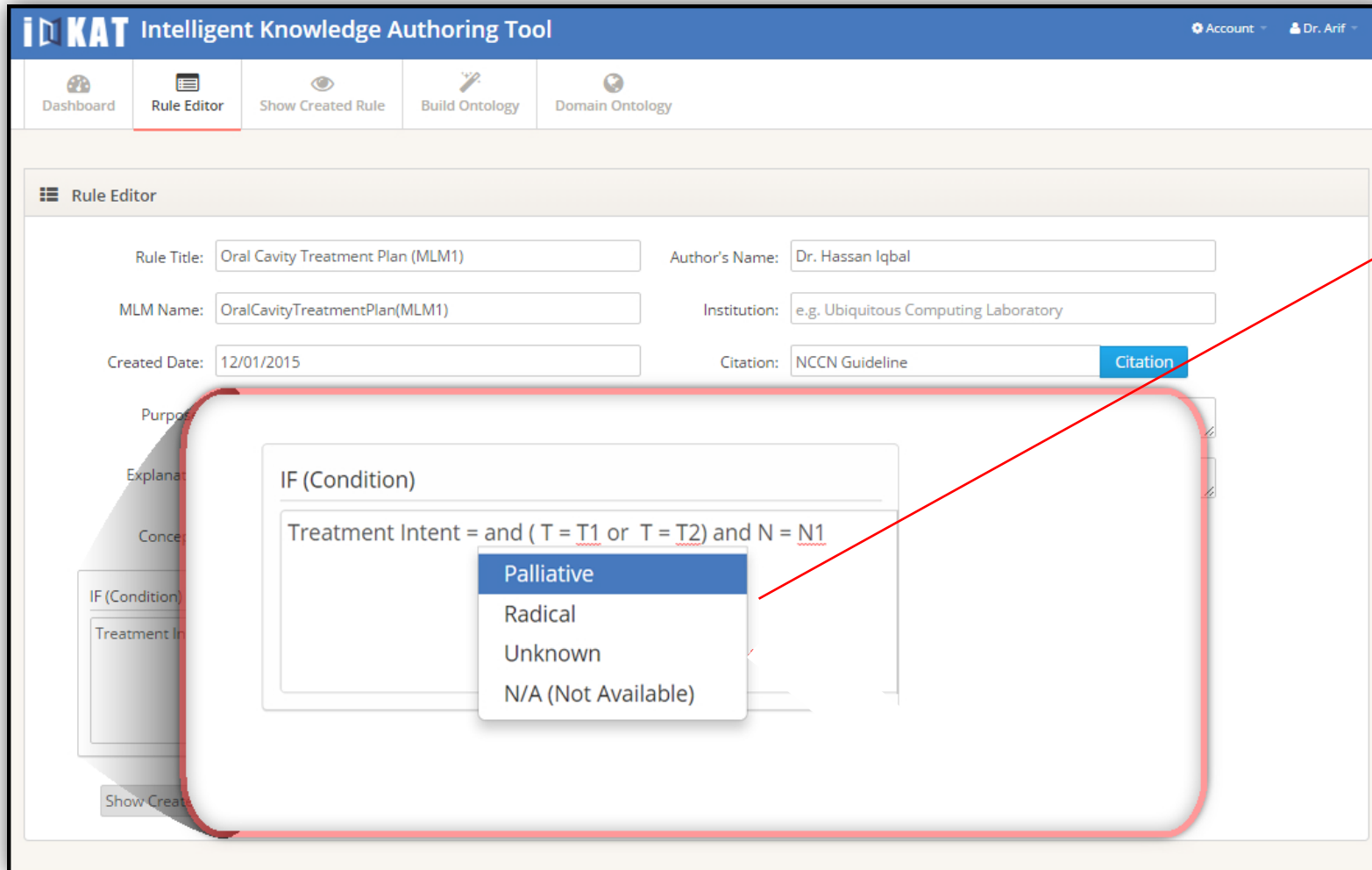
- **Dashboard:** facilitation for domain expert to view existing rules at a glance.
- **Create New Rule:** it is used to navigate domain expert to new rule creation environment
- **View:** it is used to view and modify the existing rules.



The screenshot displays the KAT Intelligent Knowledge Authoring Tool interface. It is divided into three main sections:

- Meta Information:** A form at the top for entering rule metadata. Fields include Rule Title (Oral Cavity Treatment Plan (MLM1)), Author's Name (Dr. Hassan Iqbal), MLM Name (OralCavityTreatmentPlan(MLM1)), Institution (e.g. Ubiquitous Computing Laboratory), Created Date (12/01/2015), Citation (NCCN Guideline), Purpose (Find the treatment plan for Oral Cavity), and Explanation (treatment plan for Oral Cavity using Radical and clinical staging).
- Plane Rule:** A section for defining the rule logic. It has two columns: IF (Condition) and THEN (Action). The condition is "Treatment Intent = Radical and (T = T1 or T = T2) and N = N1". The action is "Treatment Plan = Surgery; Treatment Plan = RT".
- Domain Model:** A hierarchical tree view on the left showing domain concepts. The tree is expanded to show "H and N Cancer" with sub-categories like "Treatment", "Lymph Nodes", "Surgery Pathology", "Surgery", "Radiotherapy", "Treatment Plan", "Treatment Intent", "ECOG", "Staging", "Diagnosis", and "Demographics History".

- **Meta Information:** Information about rule's title, author, specialist, creation date, purpose, and explanation.
- **Plane Rule:** it is used to enter
 - Rule condition
 - Rule conclusion/Action
- **Domain Model:** it facilitates experts to select desired standard domain concepts and values for rule condition and conclusion.



The screenshot displays the iKAT Intelligent Knowledge Authoring Tool interface. The top navigation bar includes 'Dashboard', 'Rule Editor', 'Show Created Rule', 'Build Ontology', and 'Domain Ontology'. The 'Rule Editor' section contains several input fields: 'Rule Title' (Oral Cavity Treatment Plan (MLM1)), 'Author's Name' (Dr. Hassan Iqbal), 'MLM Name' (OralCavityTreatmentPlan(MLM1)), 'Institution' (e.g. Ubiquitous Computing Laboratory), 'Created Date' (12/01/2015), and 'Citation' (NCCN Guideline). A red box highlights the 'IF (Condition)' section, which contains the text 'Treatment Intent = and (T = T1 or T = T2) and N = N1'. A dropdown menu is open over the 'N1' value, showing options: 'Palliative', 'Radical', 'Unknown', and 'N/A (Not Available)'. A red arrow points from the dropdown menu to the text box on the right.

- **Intelli-sense:** This functionality facilitates expert to select desired concepts and values in condition and conclusion writing at run time.
- It fetches concepts from domain model as well as standard terminologies of SNOMED CT.

SNOMED CT

vMR

```
knowledge:
type: data-driven;;
data:
  ProcedureEvents := object [ProcedureEvent];
  ObservationResults := object [ObservationResult, ObservationResult];
  ProcedureEventList := read as ProcedureEvents TreatmentIntent
  ( select ProcedureEvent FROM client Where ProcedureEvent.procedureCode IN ("395077000","385382003") );
  ObservationResultList := read as ObservationResults Stages T, T, N
  ( select ObservationResult FROM client Where ObservationResult.observationFocus IN ("385356007",
  "385356007", "385382003") );

logic:
  ProcedureEventListDetail := EXTRACT ATTRIBUTE NAMES ProcedureEventList;
  ObservationResultListDetail := EXTRACT ATTRIBUTE NAMES ObservationResultList;

  ProcedureEvent1 := ATTRIBUTE ProcedureEventListDetail[1] FROM ProcedureEventList;
  ObservationResult1 := ATTRIBUTE ObservationResultListDetail[1] FROM ObservationResultList;
  ObservationResult2 := ATTRIBUTE ObservationResultListDetail[2] FROM ObservationResultList;
  ObservationResult3 := ATTRIBUTE ObservationResultListDetail[3] FROM ObservationResultList;

  IF( (ProcedureEvent1.procedureCode = "395077000" And ProcedureEvent1.procedureMethod = "27762005") AND(
  (ObservationResult1.observationFocus = "385356007" And ObservationResult1.observationValue = "24351008" OR T1
  (ObservationResult2.observationFocus = "385356007" And ObservationResult2.observationValue = "67673008") AND T2
  (ObservationResult3.observationFocus = "385382003" And ObservationResult3.observationValue = "53623008" ) N1
  ) THEN
  recPart1 := new ProcedureEvent with "387713003";

  action:
  For recommendations IN recommendationList DO
  IF( recommendations IS ProcedureEvent ) THEN
  WRITE recommendations.procedureCode;
  ELSEIF ( recommendations IS ObservationResult ) THEN
  WRITE "Observation: " || recommendations.observationFocus || " Observation Value: " || recommendations.observationValue;
  ELSEIF ( recommendations IS Problem )
  WRITE recommendations.problemCode;
```

Data Slot

Logic Slot

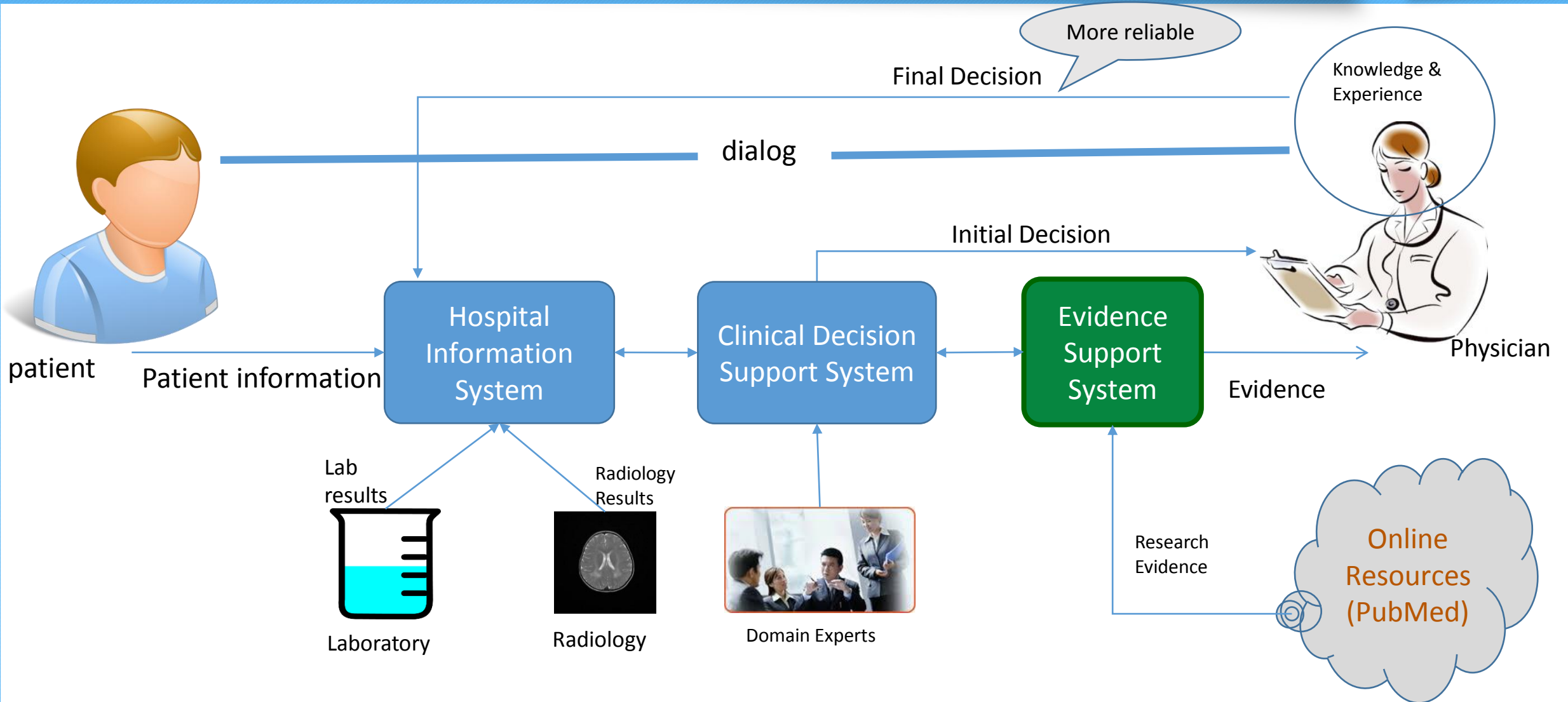
Action Slot

- **Data Slot:** This slot represents the input data that requires from HGIS system to execute this MLM.
 - The input data in form of data model vMR and SNOMED CT codes enhances shareability and makes the integration easy.
- **Logic Slot:** This is main logic slot that represents all the conditions of created rule.
 - This slot also represent the conditions in combination of vMR and SNOMED CT.
- **Action Slot:** It represent final output of executed MLM in form of recommendation (conclusion).
 - This slot can represent in data model vMR or it can be some textual recommendation.

Evidence Support



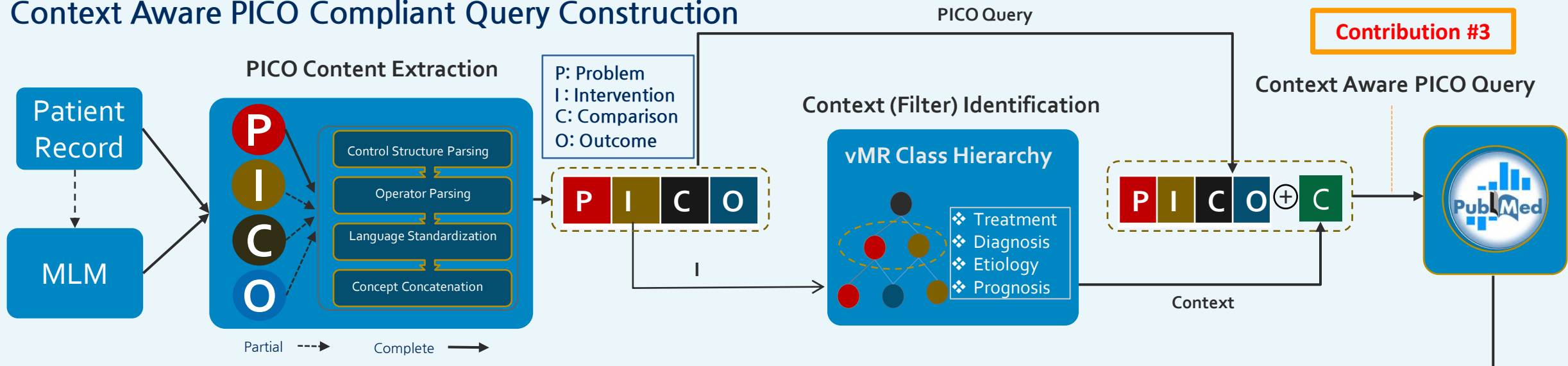
Introduction to Evidence Support



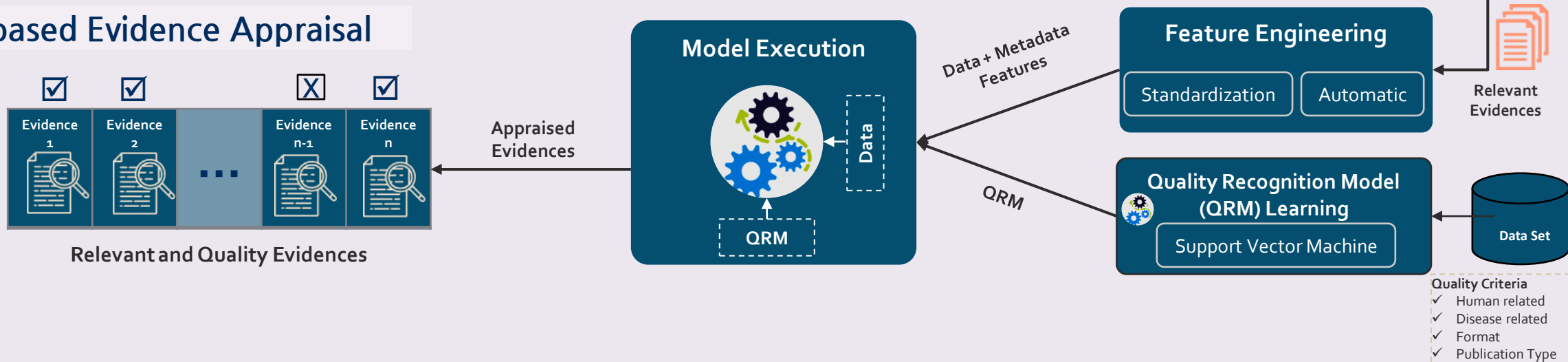
Summary of Evidence-based Knowledge Evolution



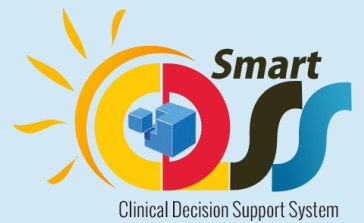
Context Aware PICO Compliant Query Construction

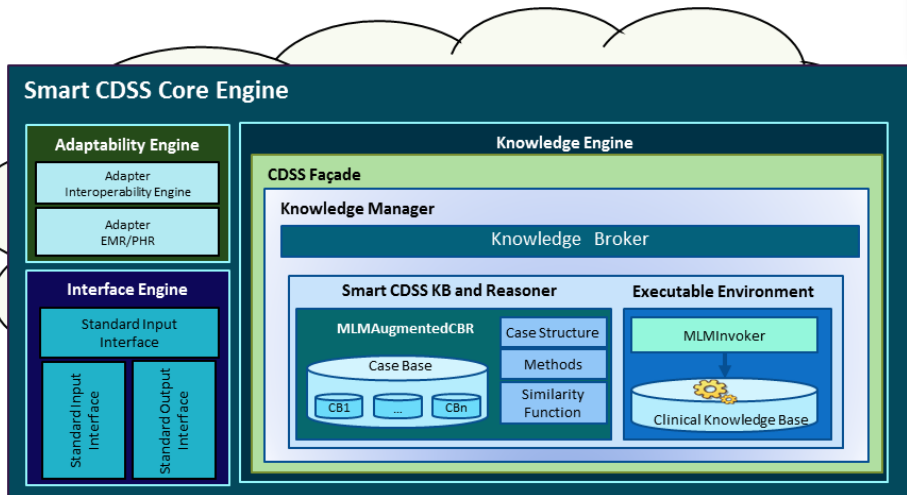


QRM-based Evidence Appraisal



Execution Engine





Adaptability Engine

- Adaptability Engine (AE) provides set of adapters to support integration with HIS
- Existing AE enables HL7 based HIS communication
- AE also support adapters to plug-in proprietary EMR

Interface Engine

Knowledge Engine

Adaptability Engine

- Interface Engine (IE) provides standard interfaces for Smart CDSS
- Smart CDSS is adapting HL7 vMR as standard for internal data model

Interface Engine

Knowledge Engine

Adaptability Engine

- Knowledge Engine (KE) provides clinical knowledge base, which is set of MLM(Medical Logic Modules)
- MLMs are represented in HL7 Arden Syntax
- KE is provided with MLMAugmentedCBR: a case base reasoning mechanism to validate and verify the clinical knowledge at runtime

Interface Engine

Knowledge Engine

T: Tumor
N: Lymph Nodes
M: Metastasis

Patient Encounter

Diagnosis

Biosis

T: 3
N: 1
M: 0

Stage: ????

Staging

T: 3
N: 1
M: 0

Stage: 3

Treatment Intervention

Multi Disciplinary Team

Chemotherapy Induction

- Disease Type: Non-resectable
- Drugs: Pemetrexed disodium and Oxaliplatin
- Intervention: Patients receive dose over 2 hours on day 1. Treatment repeats every 14 days for up to 4 courses.
- Intervention Result: Patient progressed before receiving 4 courses of treatment.



Chemotherapy

Surgery

Radiotherapy

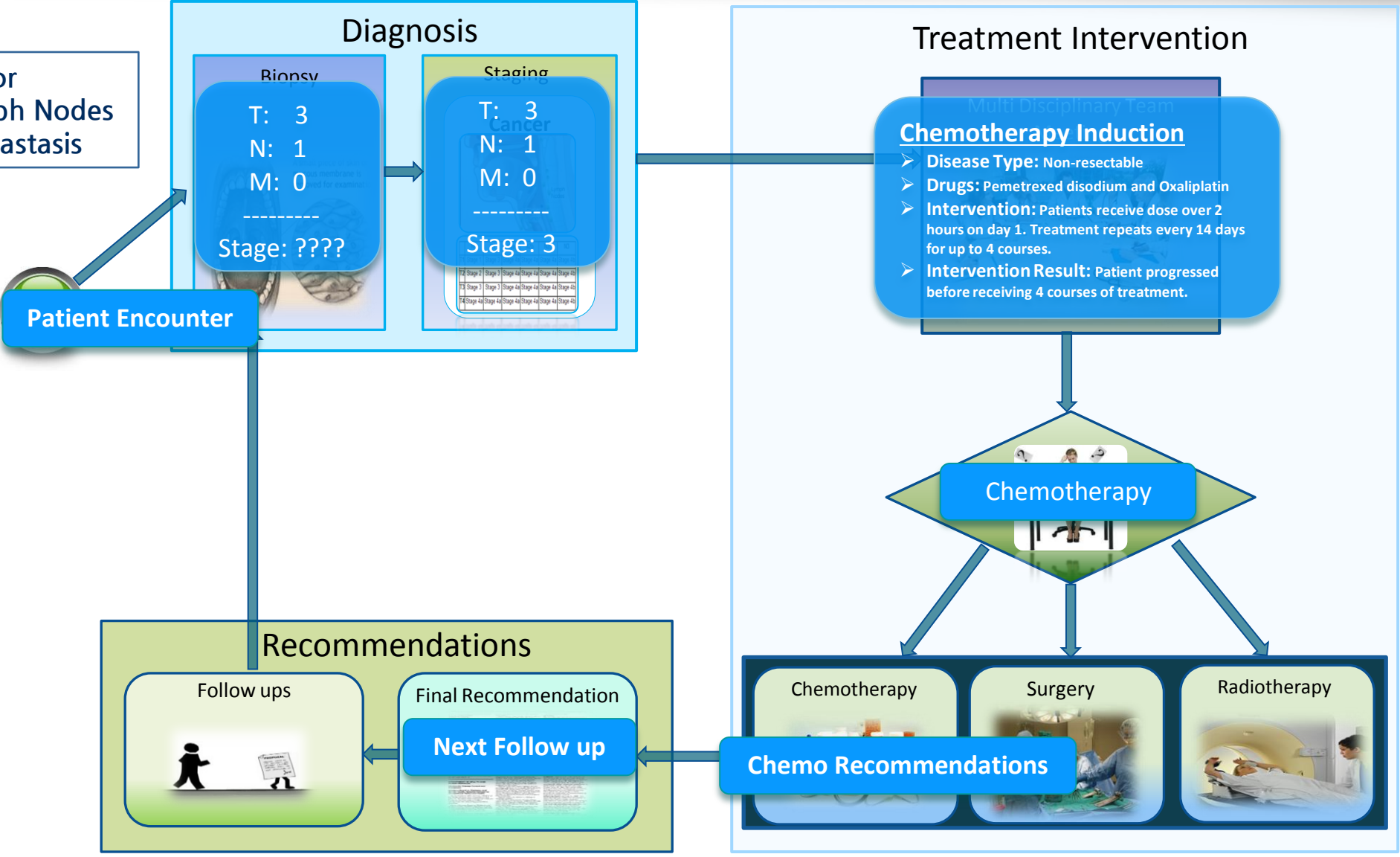
Chemo Recommendations

Recommendations

Follow ups

Final Recommendation

Next Follow up



Execution Engine: Treatment Recommendation



Hospital No Patient Name
 Start From Contains

Dashboard

- » Add New Patient And Encounter
- » Add New Encounter of existing patient
- » Reports

Patient Encounters

Registration

Hospital No
Name
Sex
Date Of Birth
Ethnicity
Smoking
Pan
Naswar
Alcohol

Current Event

Date HN
Clinic
Current Event

Treatment

Intent
Plan

Diagnosis

Site
Subsite
Date Biopsy
Histology
Grade

CDSS

Stage

0
UK
x

Radiotherapy

Start End
Dose Fractions
Response
PEG

Chemotherapy Induction

Regime
No. Cycles
Response

Chemotherapy Concurrent

Regime
No. Cycles

Chemotherapy Adjuvant

Regime
No. Cycles

Chemotherapy Palliative 1st Line

Regime
Duration

Chemotherapy Palliative 2nd Line Line

Regime
Duration

Surgery Pathology

Surgical Margins
Perineural_I
Lymphovascular_I
Bone/Cartilate I
Extracapsular_E

Lymph Nodes

Level	I	II	III	IV	V
Ip R					
Ip P					
Con R					
Con P					
TLNR			TLNP		

Failure

Date_Rec
Site

Notes

FNA positive
Needs redo surgery. Excision of left submandibular gland with ipsilateral level II, III, IV dissection

Status

Patient Status
Date FU
Treatment Status

Information Updates

Update Status
Remarks

CDSS

2 Treatment Plan CDA Input to CDSS

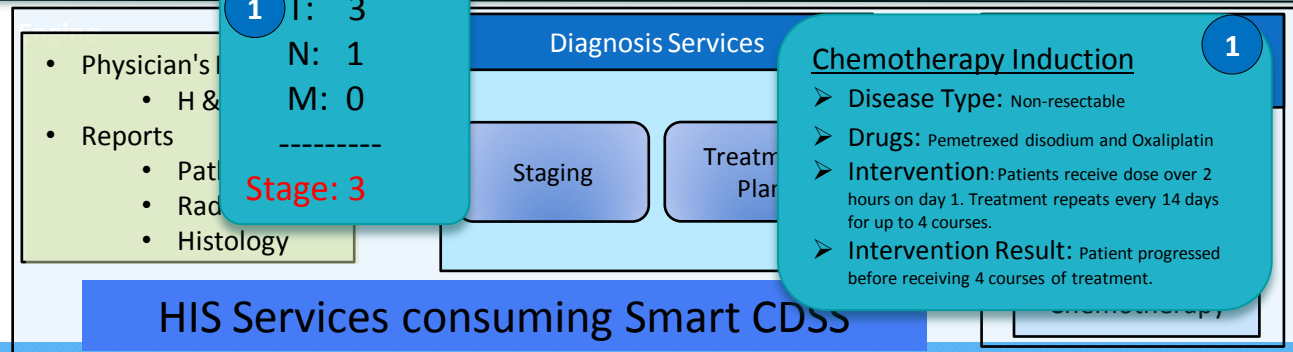
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Staging

Chemo Induction

H&N Cancer Workflow



1 T: 3
N: 1
M: 0

Stage: 3

1
Chemotherapy Induction
 ➤ Disease Type: Non-resectable
 ➤ Drugs: Pemetrexed disodium and Oxaliplatin
 ➤ Intervention: Patients receive dose over 2 hours on day 1. Treatment repeats every 14 days for up to 4 courses.
 ➤ Intervention Result: Patient progressed before receiving 4 courses of treatment.

NCCN

HIS Services consuming Smart CDSS

Execution Engine: Treatment Recommendation



3 vMR converted from CDA

```

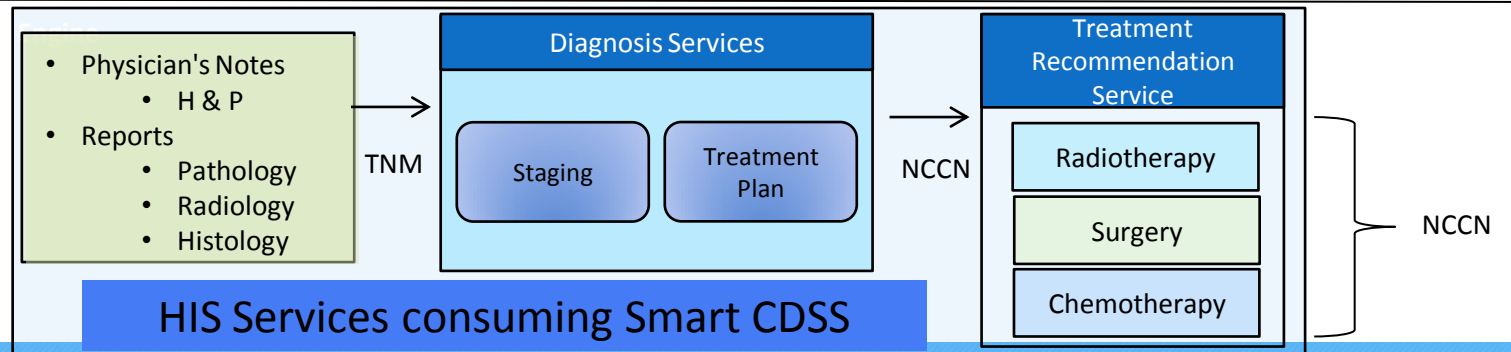
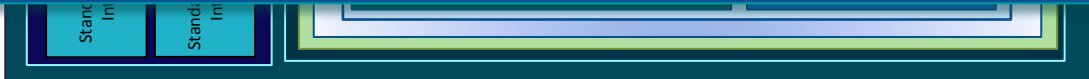
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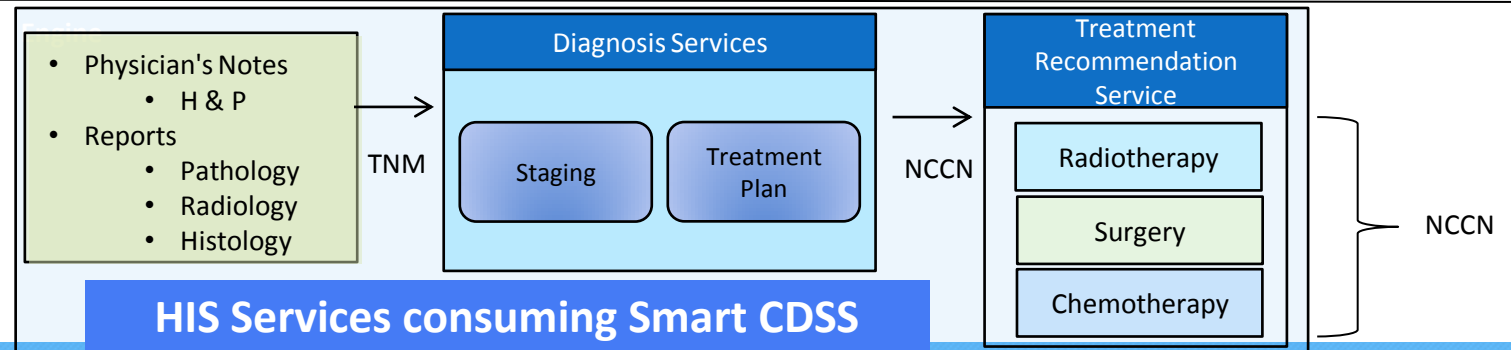
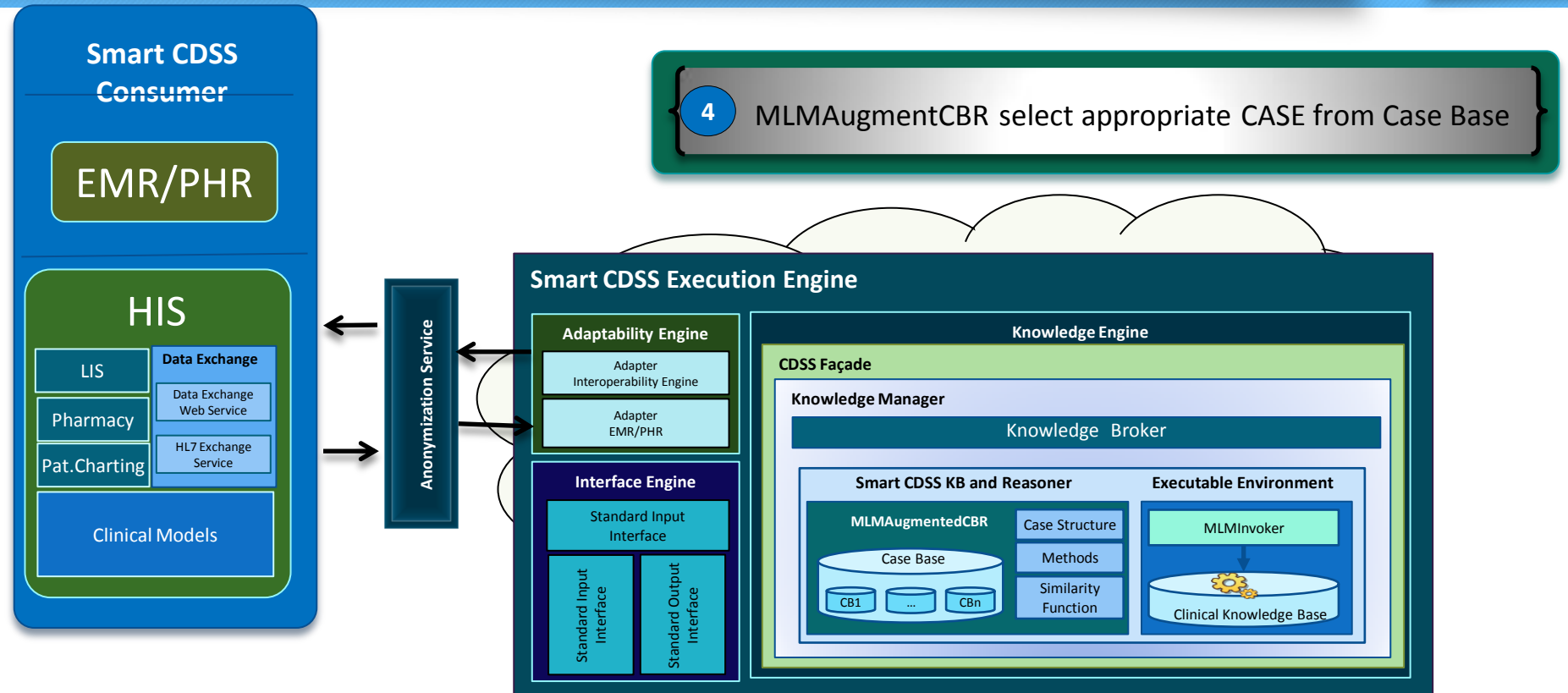
Staging

```

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```

Chemo Induction





5 Base on CASE selected, Treatment Plan MLM is executed

maintenance:

title: Treatment Plan MLM for Lips and Cavity

... ..

library:

purpose: "Taking Staging and Chemo Induction for lips and cavity cancer and suggest appropriate Treatment Plan for patient"

knowledge:

logic:

If S = 3 and Disease type = Resectional and Drug1 = Oxaliplatin and Drug2 = Pemetrexed and Intervention Result= Patient progress before ending of 4 courses

then

Treatment Plan = Concurrent Chemo-Radiotherapy;

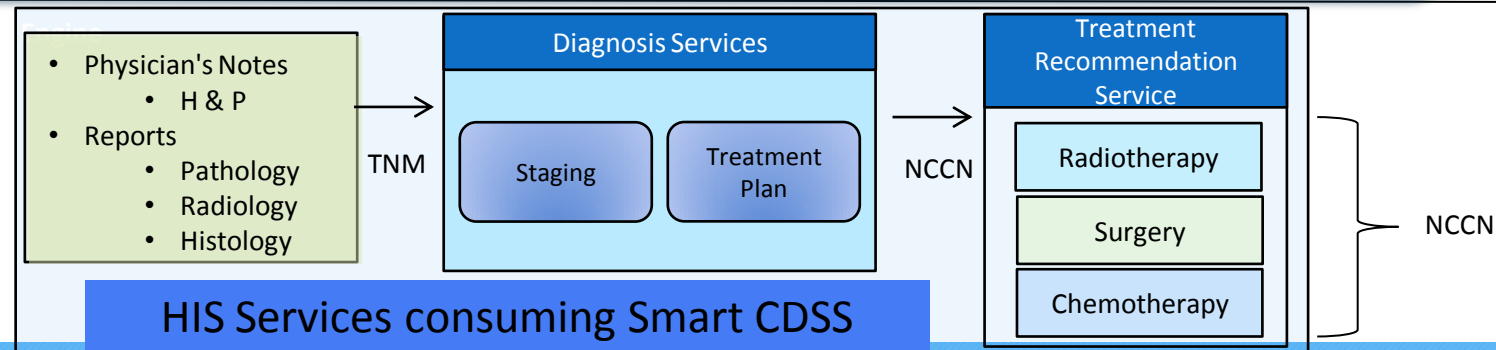
Else if S = 3 and Disease type = Non-Resectional and Drug1 = Oxaliplatin and Drug2 = Pemetrexed and Intervention Result= Patient progress before ending of 4 course **then**

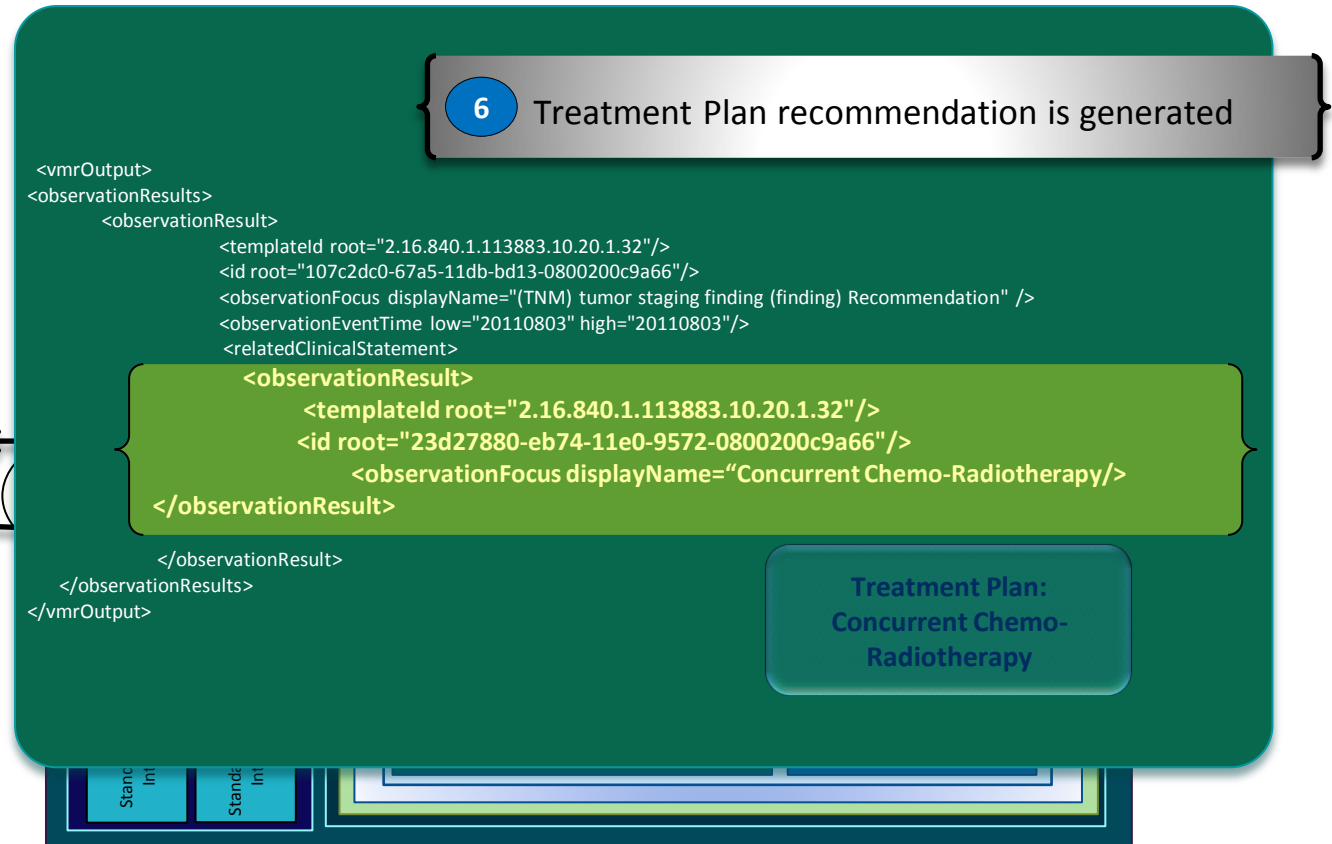
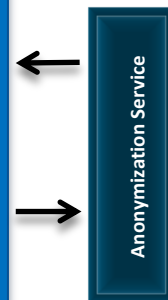
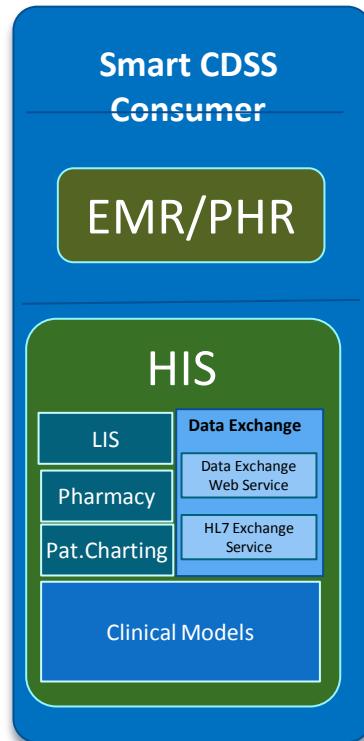
Treatment Plan = Surgery

Else if -----

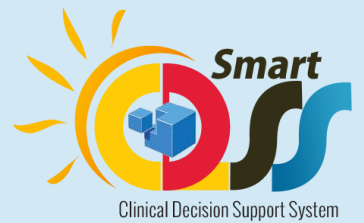
....

End;;






Summary



HEAD AND NECK CANCER DATA INTEGRATION



INTEGRATION OF
5100 PATIENTS
RECORDS of SKMCH WITH
SMART CDSS




PRIMITIVE SHAREABLE RULES
(MLM) CREATION




NCCN based

Oral Cavity + Salivary Gland

TREATMENT INTERVENTION IS HANDLED BY SMART CDSS



EVERY WEEK




on average
125 PATIENTS
records are enabled for decision support in SKMCH



WHAT WE **ACHIEVED**
IN THE **LAST 4 YEARS**

PERFORMANCE OF PHYSICIANS WERE ENHANCED
26 TIMES
IN CREATION OF RULES

The error rates RECORDED
1 per MLM while for other tools it was **11 per MLM** creation



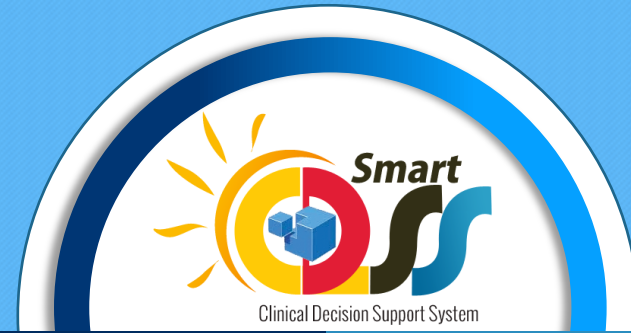


▪ Knowledge Acquisition & Authoring

- **Three phase knowledge acquisition model** combined data-driven with guidelines
 - Producing guideline enabled data acquisition : **72% accuracy on real patient data**
- KAT enhanced physician performance by **26 times as compared to ArdenSuite**
- Automatic Generation of PICO compliant Query and Automatic Quality Appraisal: **Time saving and 35% documents are filtered out.**

▪ Execution Engine

- Provides set of **healthcare standards adapters** such as HL7 CDA and HL7 FHIR
- Provides **standard interfaces** using HL7 vMR



Thanks

Sungyoung Lee, Kyung Hee University, Korea

URL: <http://uclab.khu.ac.kr>