Connected Health Summer School

Mobile health services and apps

25-28° June 2018 -Artimino, Firenze, Italy

Intelligent Medical Platform & Silo Construction

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Introduction to IMP (Intelligent Medical Platform): Goals

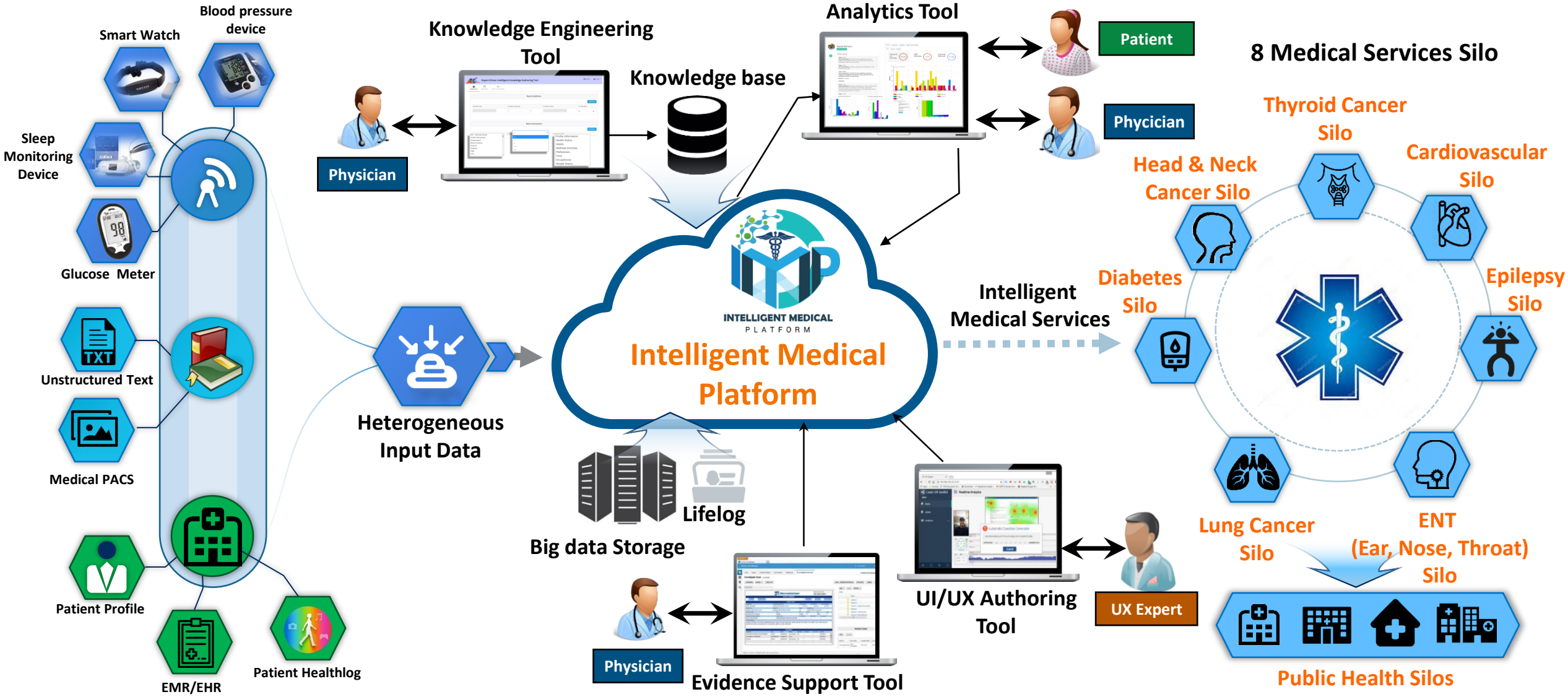
❖ AI Doctor (Intelligent Medical Expert Systems)

❖ Novel Knowledge Acquisition
(Data Driven + Expert Driven + Dialog Driven)

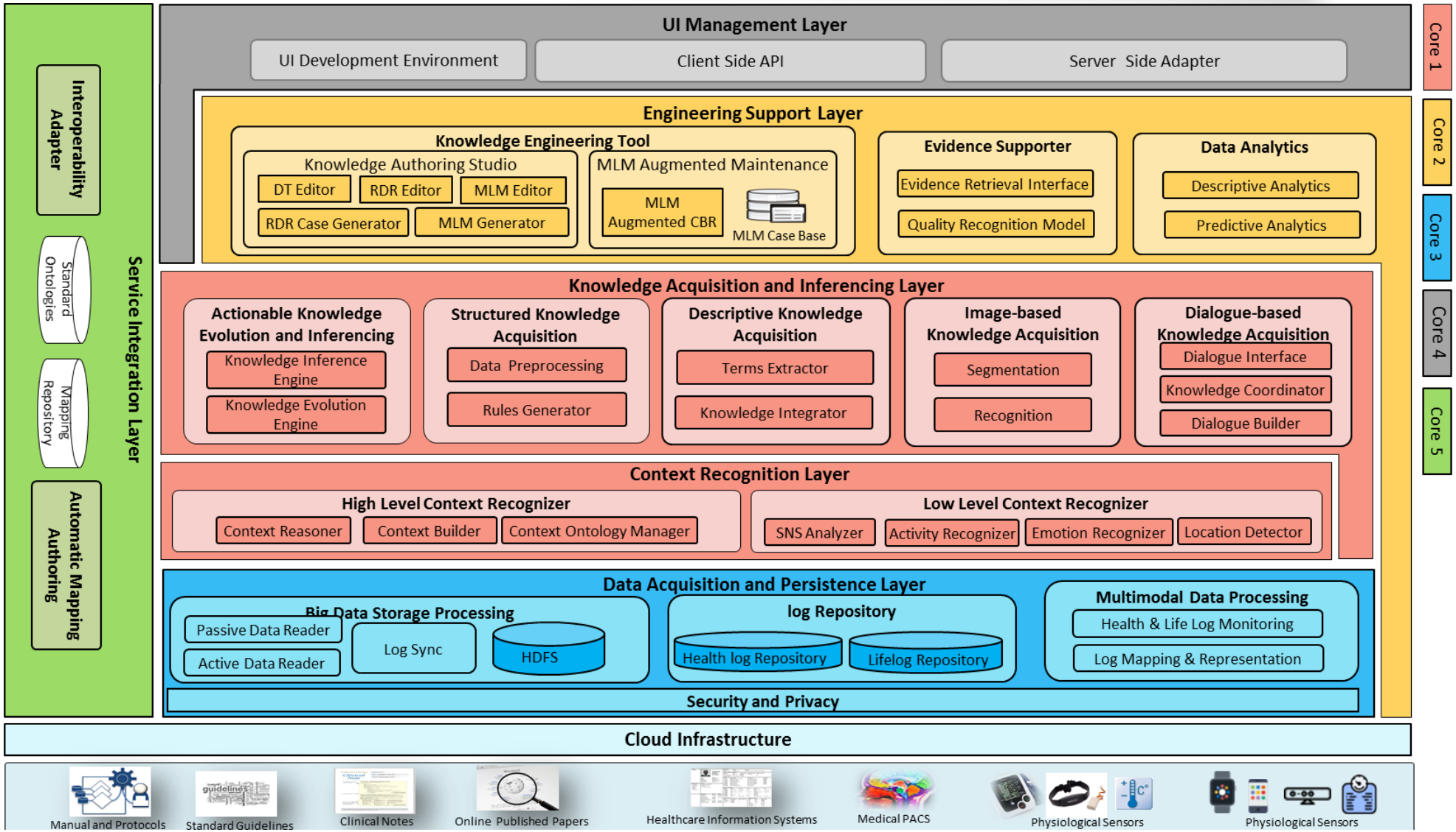
❖ Knowledge Engineering Tools
(V&V, Maintenance)

❖ Medical Knowledgebase Silo Construction

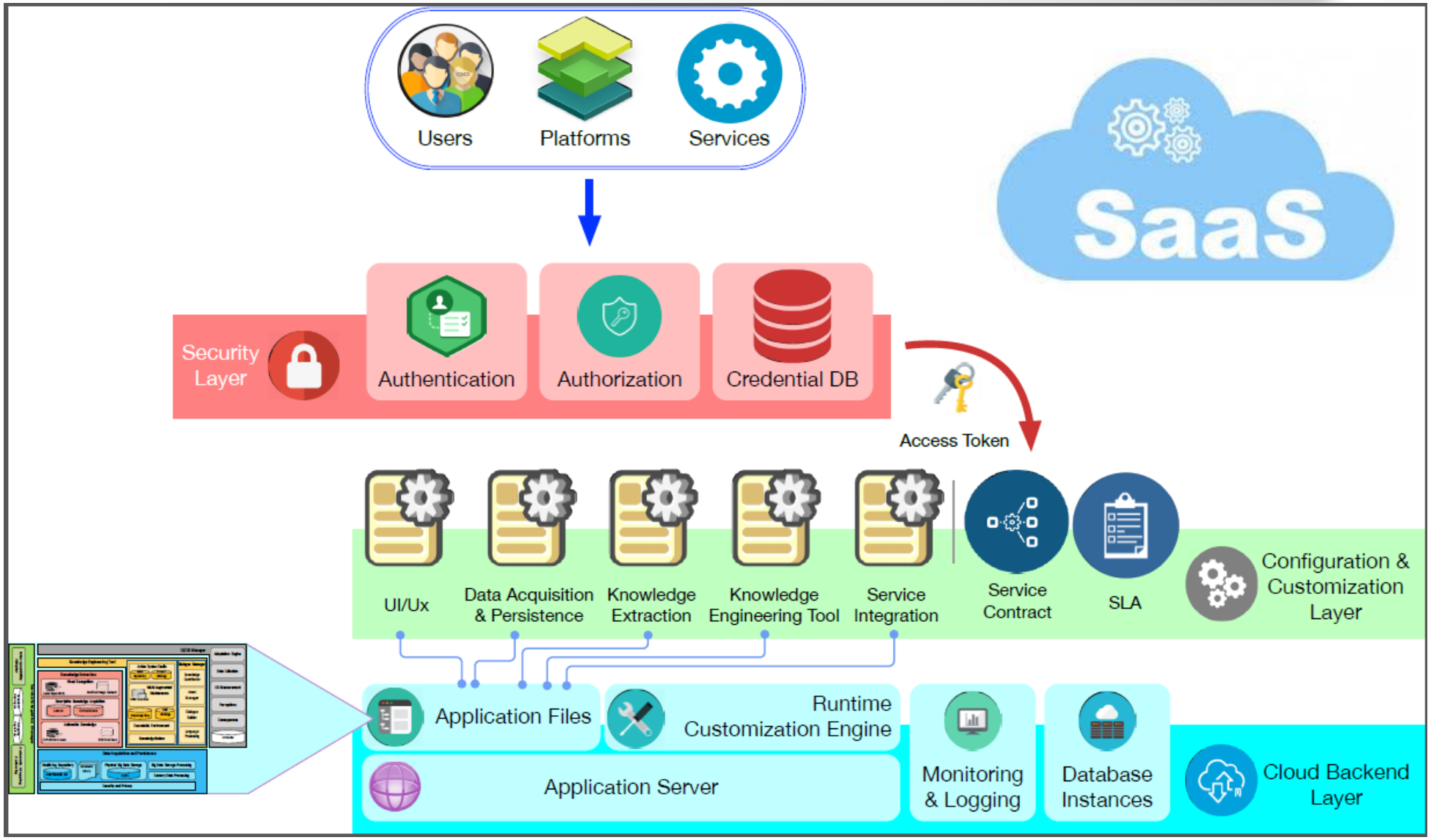
Overview of IMP



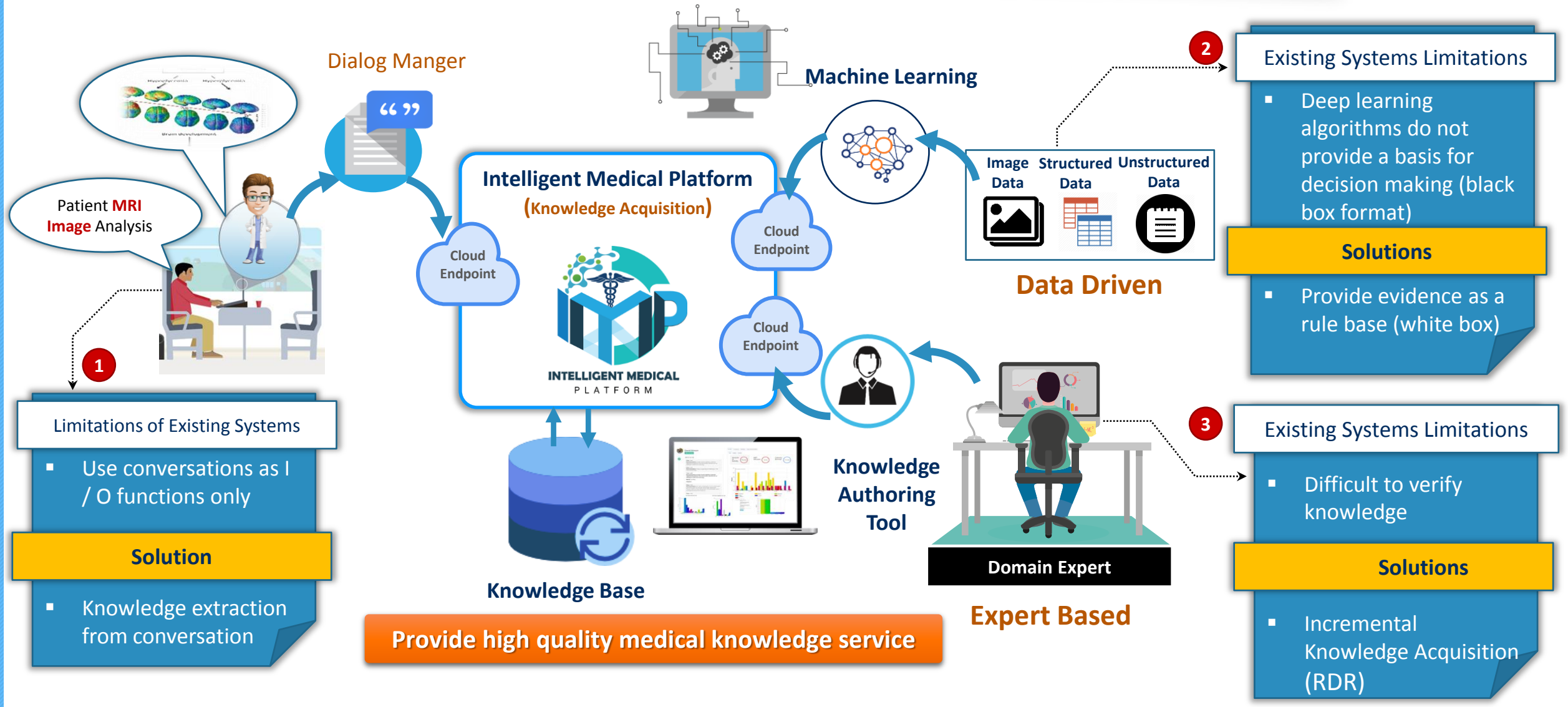
IMP Architecture



Deployment of IMP

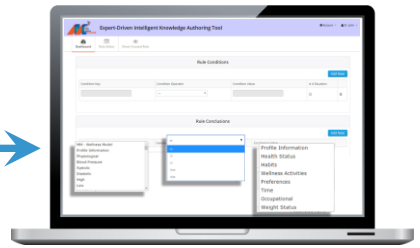


Uniqueness: Novel Knowledge Acquisition



Uniqueness: Engineering Support Environment

- Knowledge Acquisition
- Validation & Verification



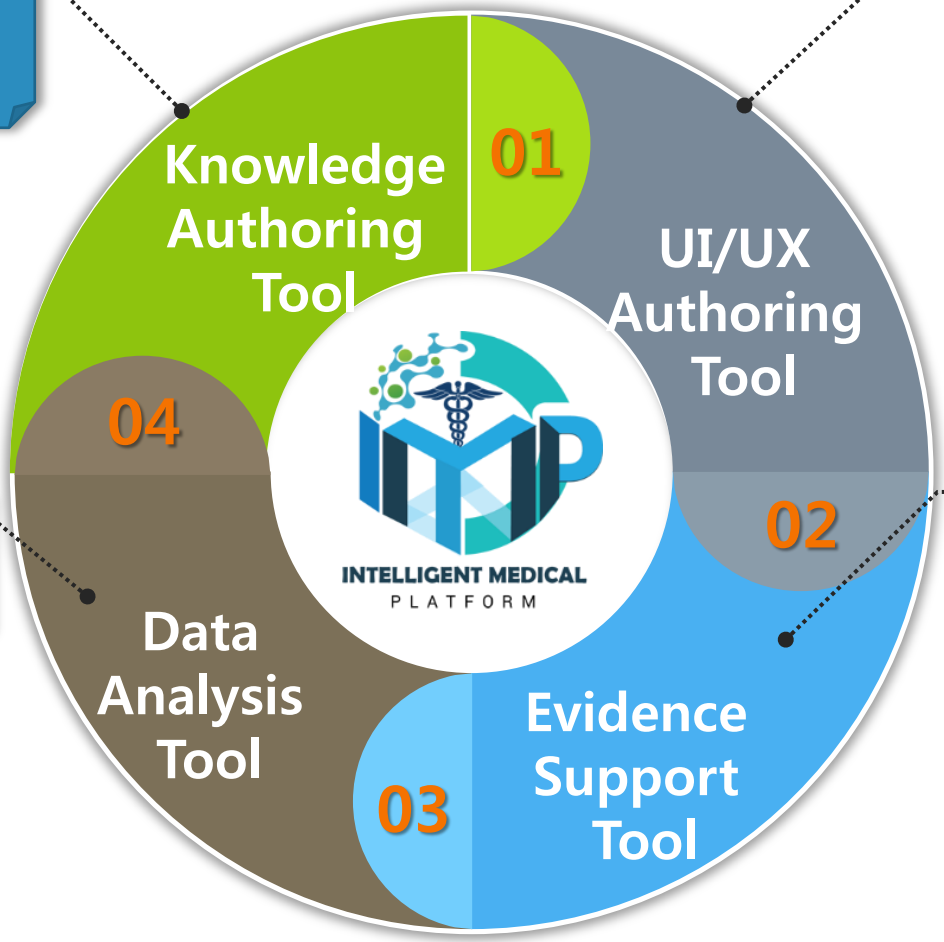
Physician

※ MCRDR: Multiple Classification Ripple Down Rule

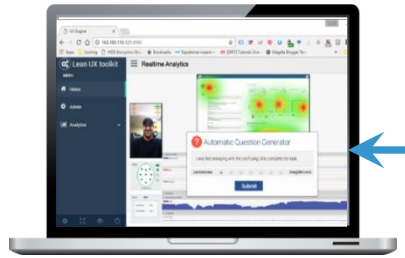
- Real-time Monitoring
- Visualization

Patient

Physician

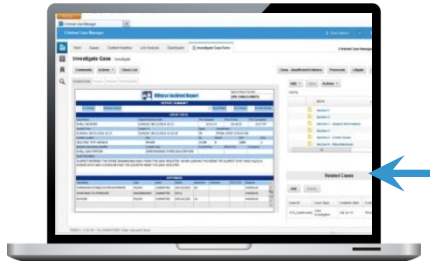


- Quantification of UX
- Adaptive UI



UX Expert

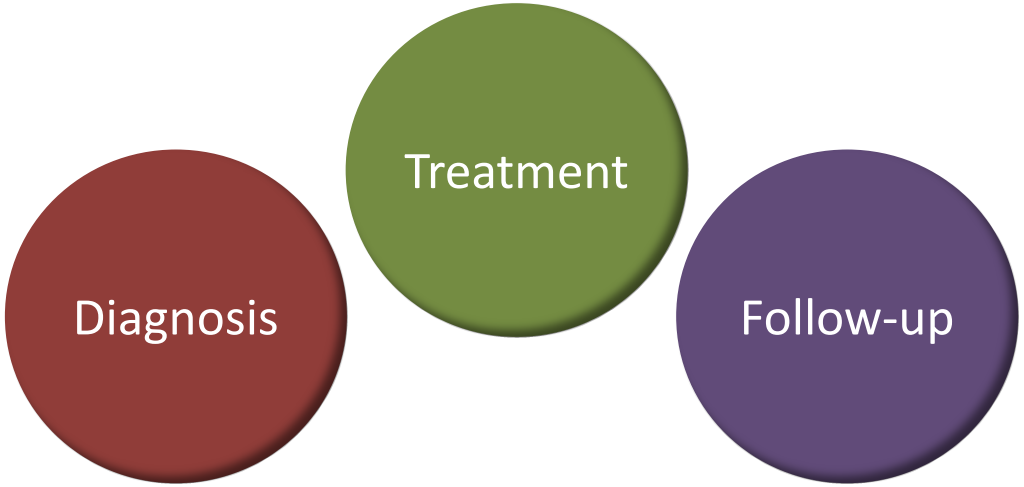
- Retrieval Documents from PubMed



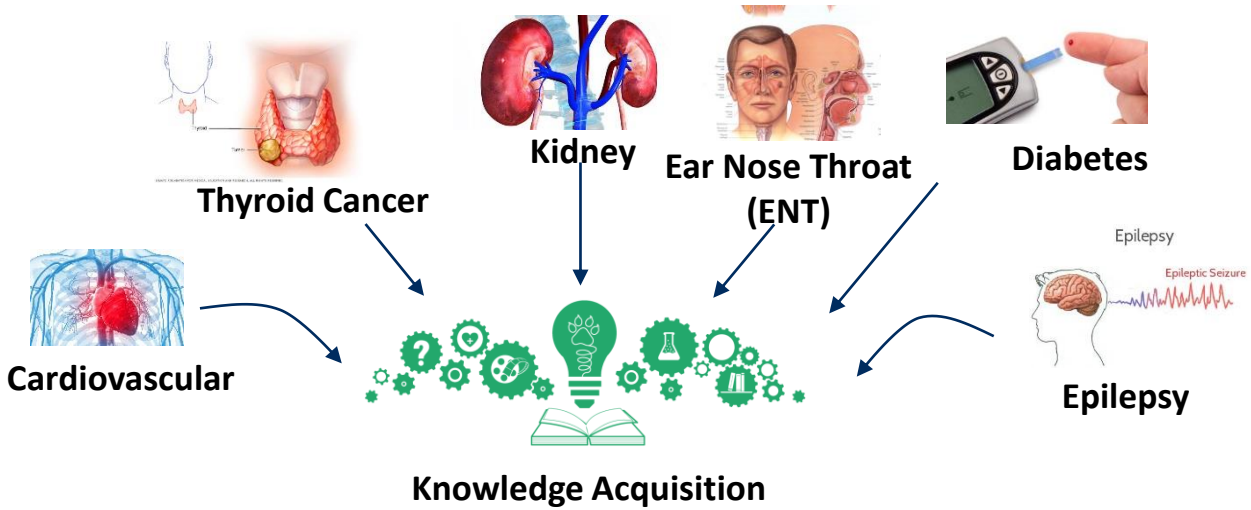
Physician

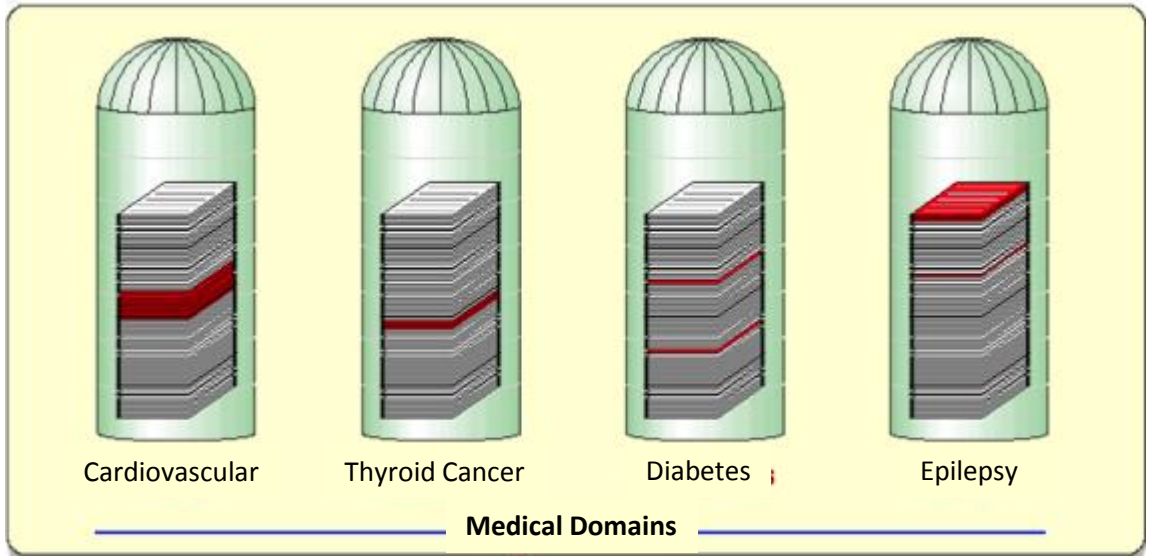
Easy to Commercialization

Introduction to Silo Construction



Silo is a structure for storing bulk materials





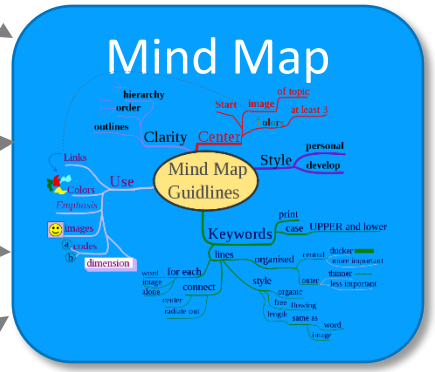
Introduction to Silo Construction

Expert Heuristics

Clinical Guideline

Published Research

EMR/EHR



Silo Construction Process

- Mind map creation
- Decision Tree Transformation
- Plain Rule Creation
- Knowledge Execution

Silos

Diagnosis

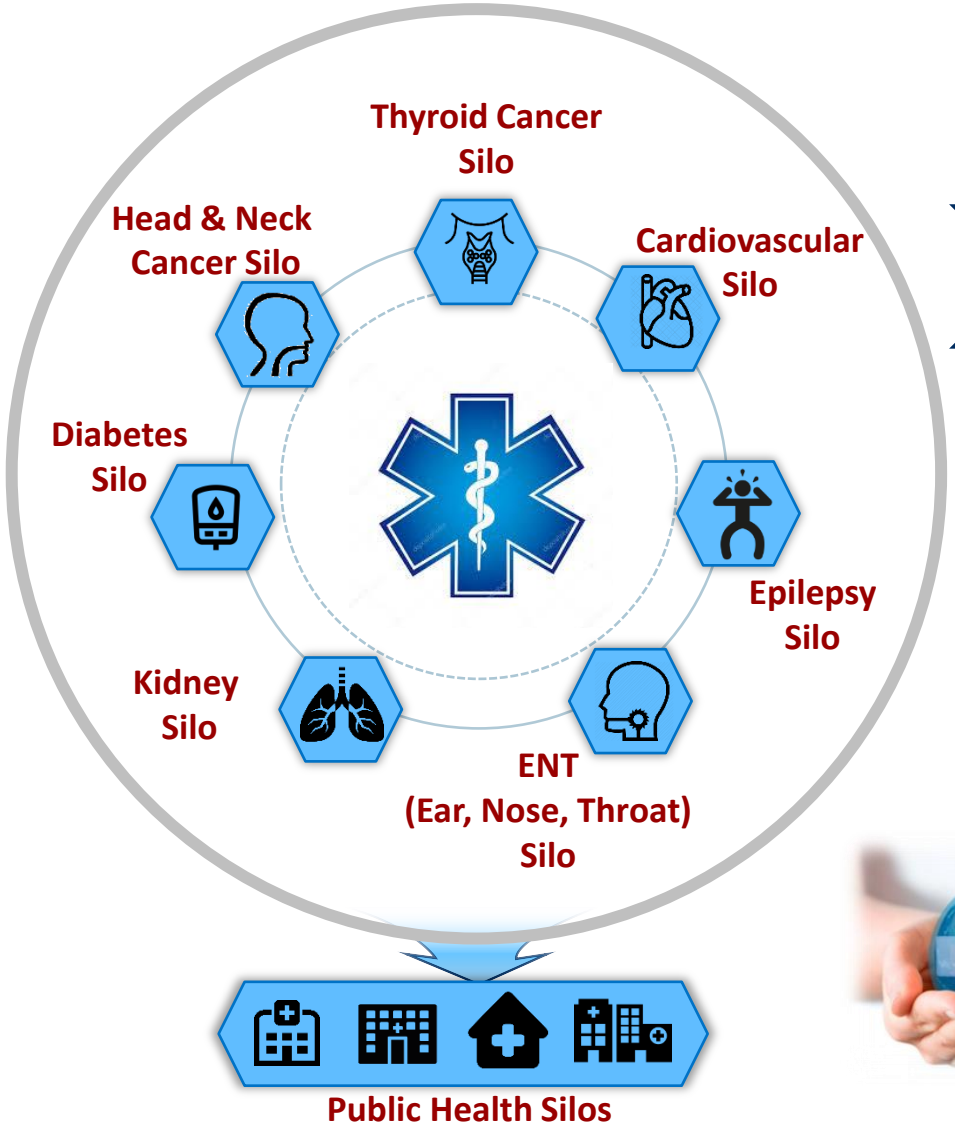
Treatment

Follow-up

Motivation

Needs

- Quality of Medical Services
- Reduce Medical Cost
- Efficiency & Safety



Expected Impacts

- Improve quality of healthcare delivery
- Save Medicare cost
- Reduce medical malpractices

Silo Development Stages

Knowledge Acquisition: Expert heuristics, guidelines, published research and existing systems are sources of domain knowledge

Knowledge Modeling: The acquired knowledge is transformed in to a formal representation such as Decision Tree

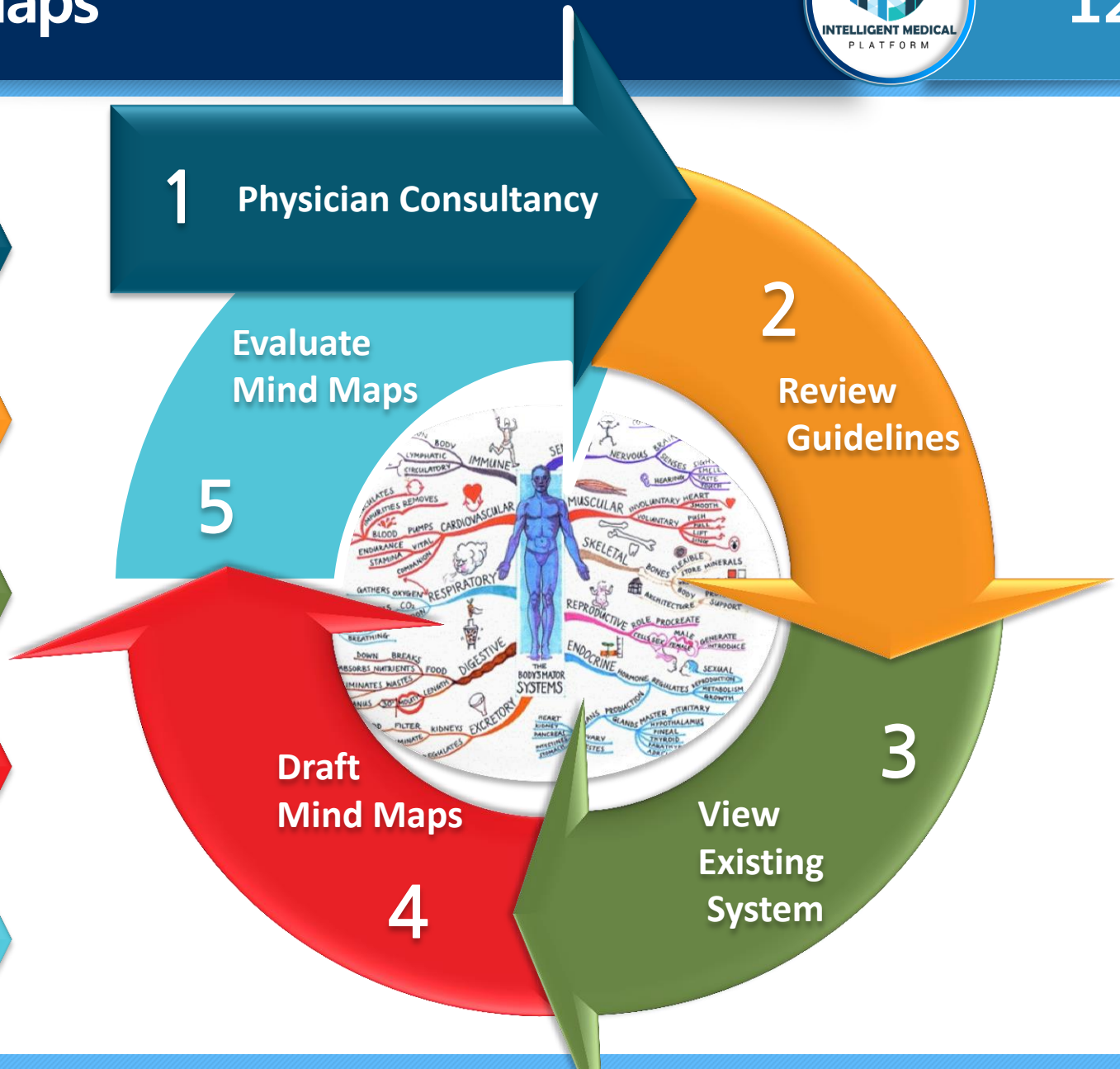
Rule Generation: Knowledge is transformed from formal representation to computer executable format i.e. Plain Rules

Implementation: A standalone executable environment is developed to execute the created knowledge for providing recommendations.

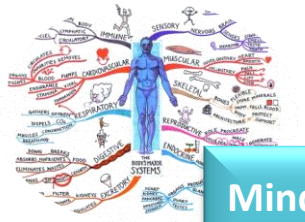
Evaluation The accuracy of the system is evaluated on the real patient data of the corresponding sub medical domain

Stage 1: Knowledge to Mind Maps

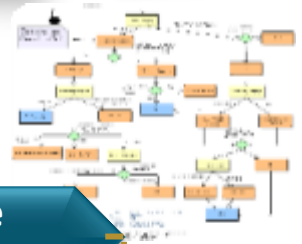
1. **Physician Consultancy**: Patient History, Symptoms, Review of Mind Maps
2. **Review Guidelines:** Medical Documents, Manuals, Published Papers
3. **Existing System:** Registration, Data attributes, Information Flow & Persistence
4. **Mind Maps:** Logical Note of Physician Expertise and knowledge
5. **Evaluate Mind Maps:** Physician evaluate the ambiguities for further improvement



Stage 2: Mind Maps to Decision Tree



Mind Map → Concepts Extraction → Concepts Prioritization → Mapping Relationship → Evaluate Decision Tree



2: Concepts Extraction

Identify all the contributing factors from the mind maps provided by the expert to comprehend the domain.

3: Concepts Prioritization

Select the most defining factors from the extracted ones to divide the flow of constraints and condition.

1: Mind Maps

Experts provide the mind maps to transform the knowledge in brain into ideas.

Concepts Prioritization

Concepts Extraction

Mapping Relationship

5: Decision Tree

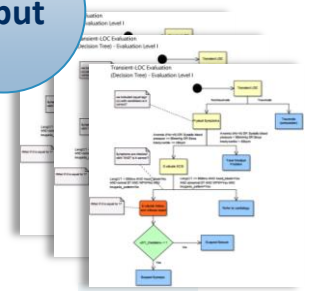
It is a model of decision and their possible consequences for the diagnosis as well as treatment.

4: Mappings Relationship

Map the contributing factor to draw the flow for diagnosis and treatment.

Stage 3: Rule Extraction

Input



1 Decision Tree

Receive verified decision tree as an input

2 *If-then* rules

Generate if-then rules from decision tree

3 Rules verification

Expert verifies the generated rules with respect to decision tree

Knowledge Engineer

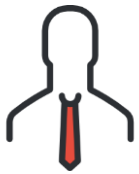
if $x_1=0$ and $x_2=1$ **then** "1"
else if $x_3=0$ and $x_2=1$ **then** "1"
else if $x_1=1$ **then** "0"
else if $x_3=1$ and $x_2=1$ **then** "1"
else "0"

Domain Expert

Output

Stage 4: Implementation

Interface Design

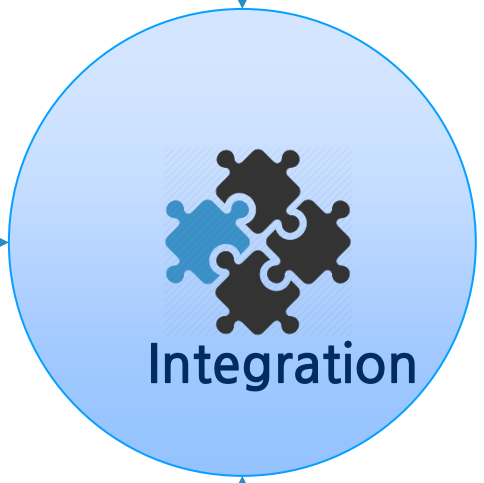


Backend Processing Engine

REST Services

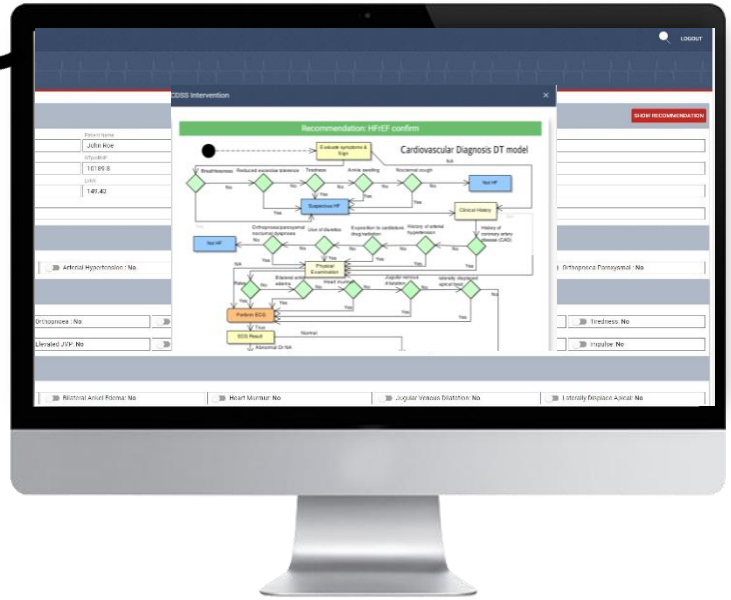
Schema Design

Knowledge Base



Testing

CDSS Intervention



Stage 5: Evaluation

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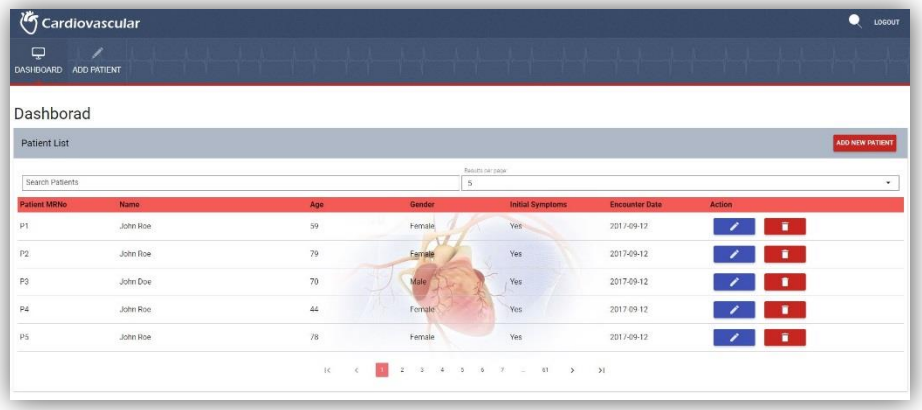
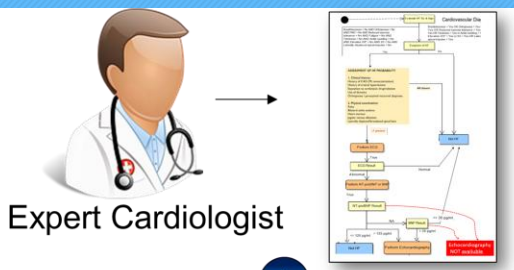
Case Study: Cardiovascular Silo

Workflow: Knowledge Creation and Recommendation



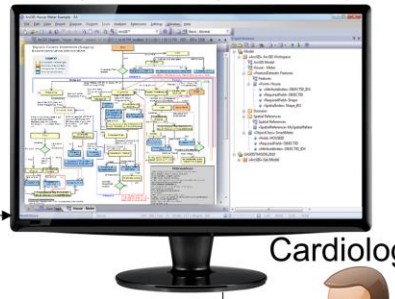


Expert Cardiologist

Knowledge Engineer

1 Create Mind Map (Cardiovascular Knowledge Model)

2 Decision Tree Creation (Knowledge Model)



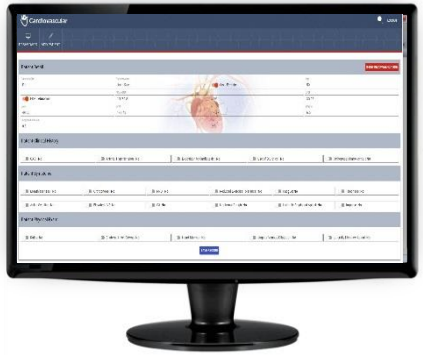
Cardiologist

Voice/text/image Dialogue

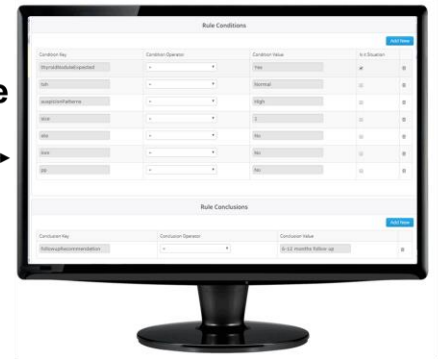
3 Cardiology **Rule Creation** and **MLM** Transformation

Voice/text/image

5 Cardiology recommendation **request**



Managing **Dialogue**



6 Cardiology treatment and diagnosis recommendation

4 Cardiology Knowledge base

Stage 1: Knowledge Acquisition

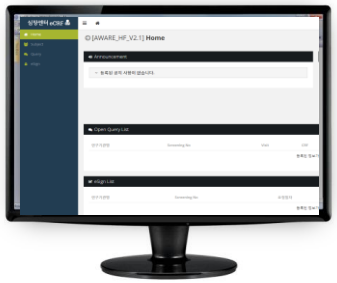
Cardiology Guideline

B Taking help from published guideline

A Physician experience and heuristics

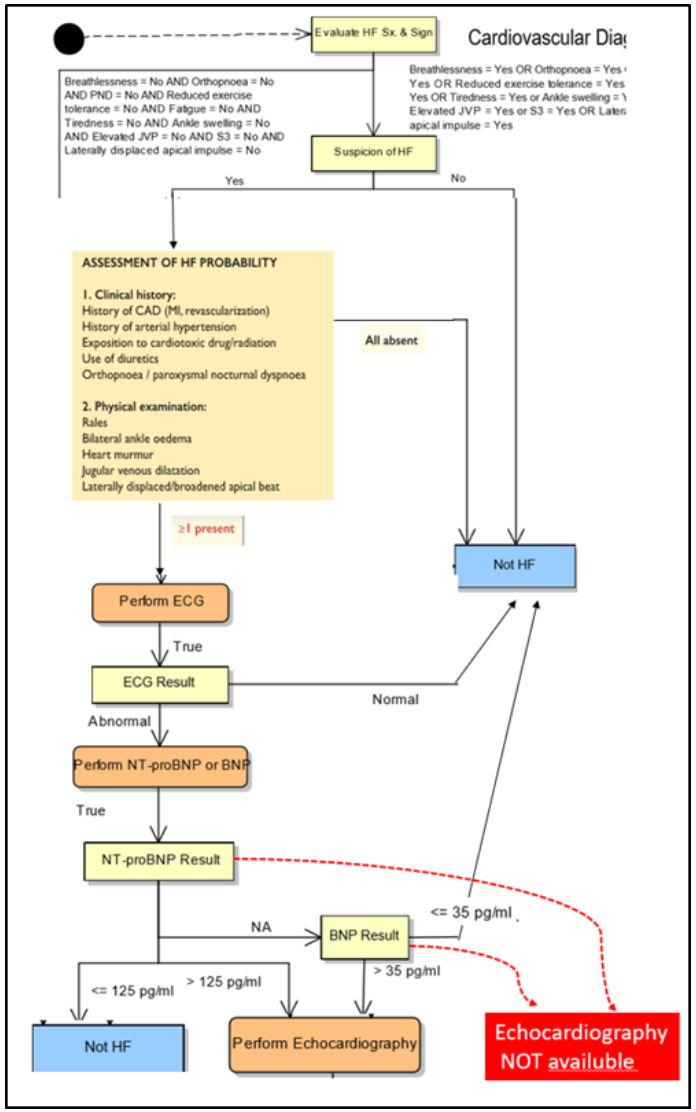
Physician

A + B + C



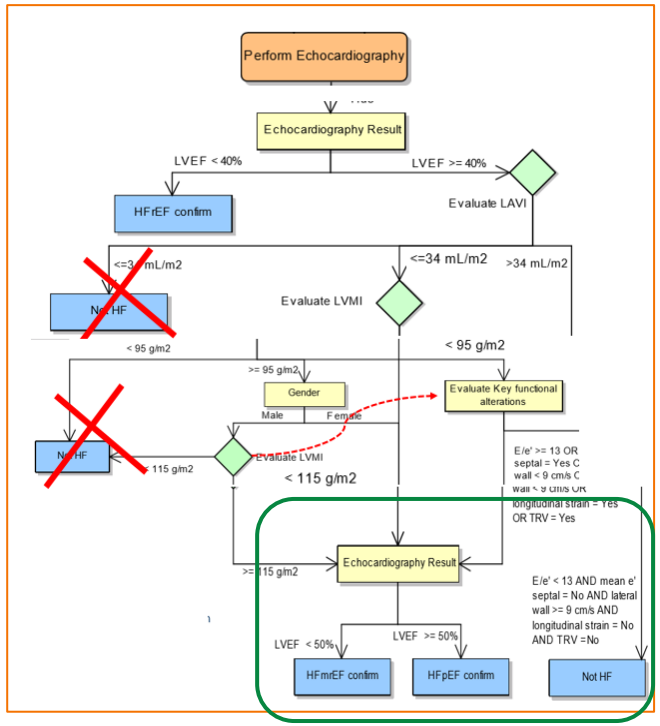
심장센터 eCRF

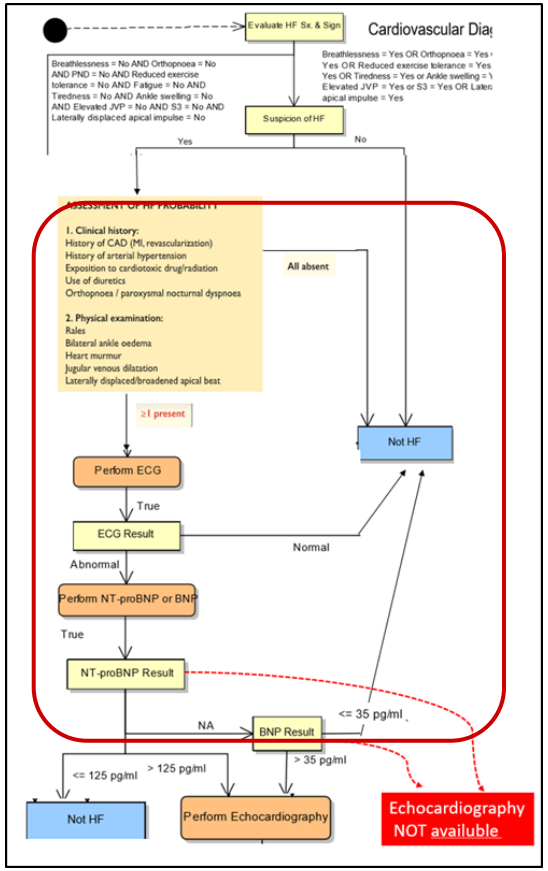
C Real practice with existing systems

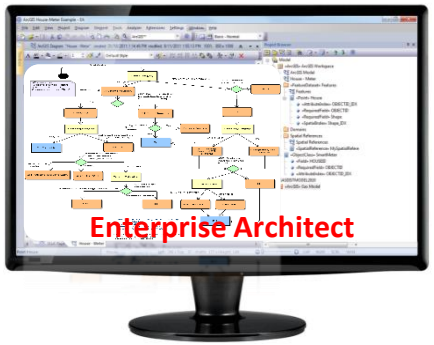


Stage 2: Knowledge Modeling

Mind Map





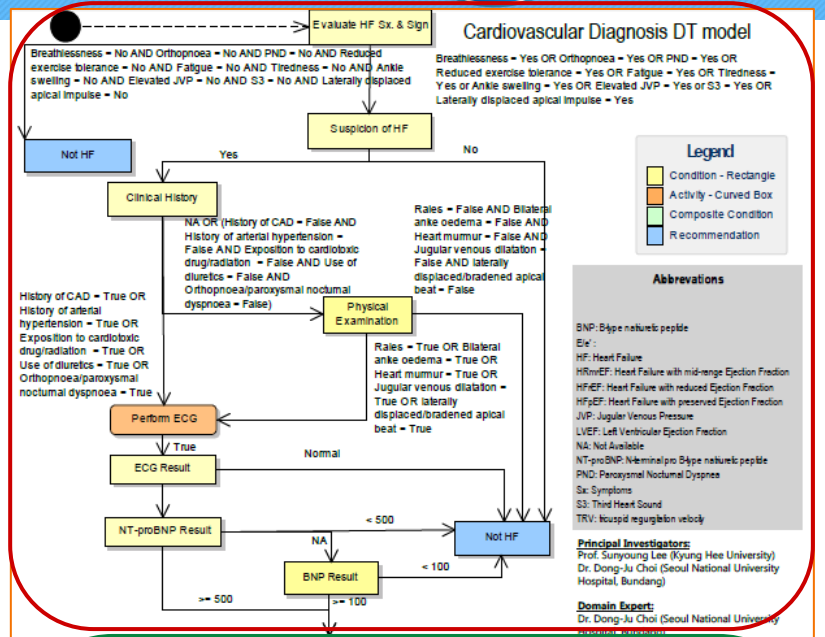


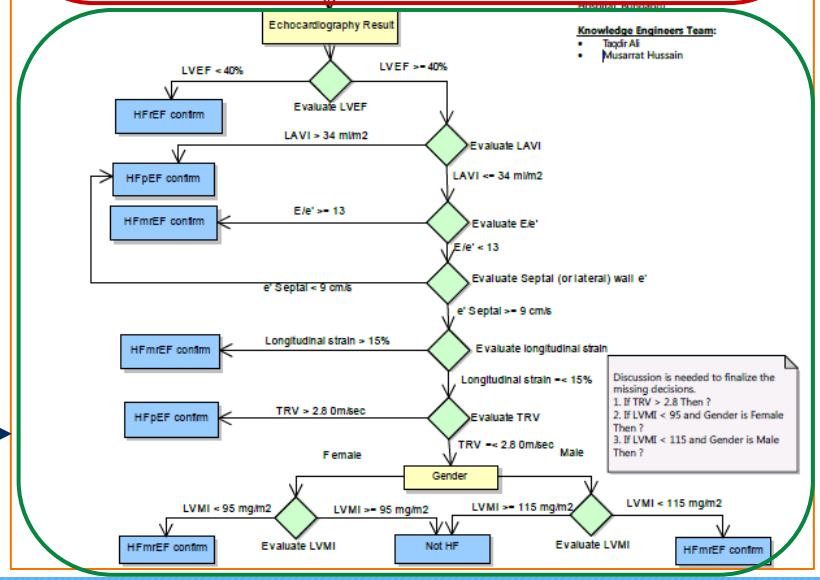
Knowledge Engineer

Intensive meetings are required iteratively.

Physician

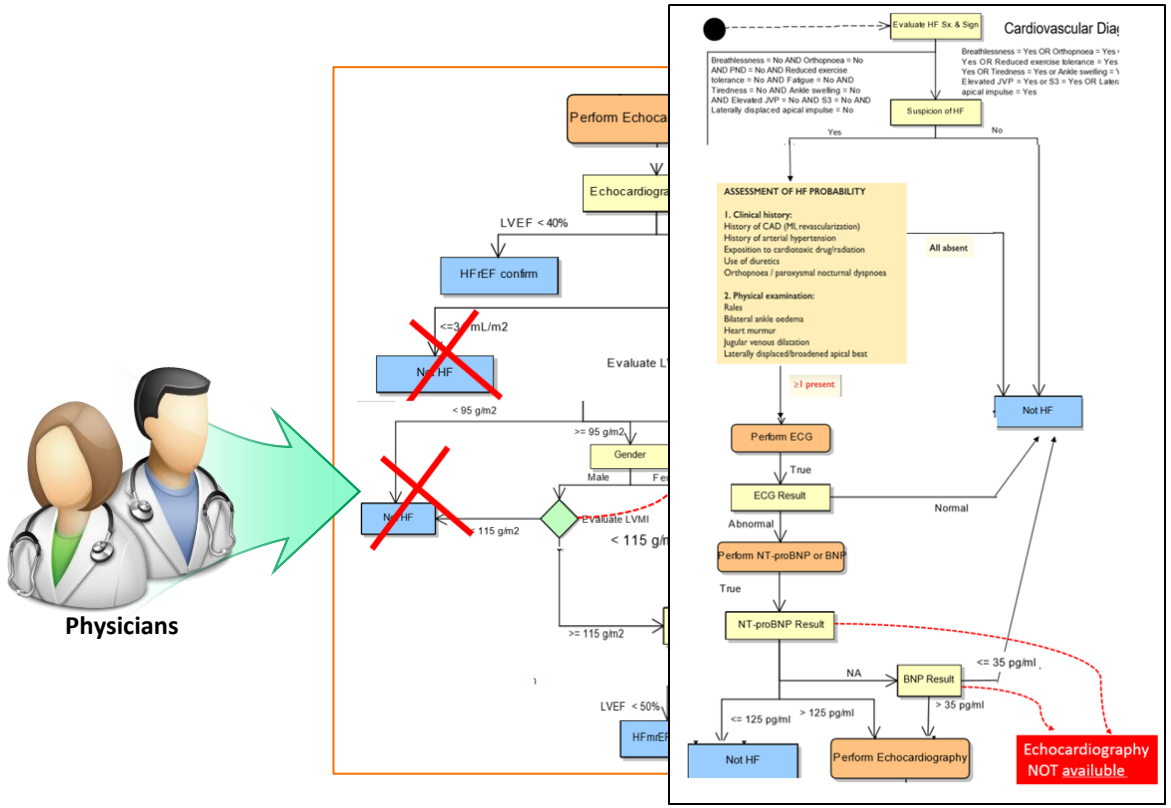
Verification





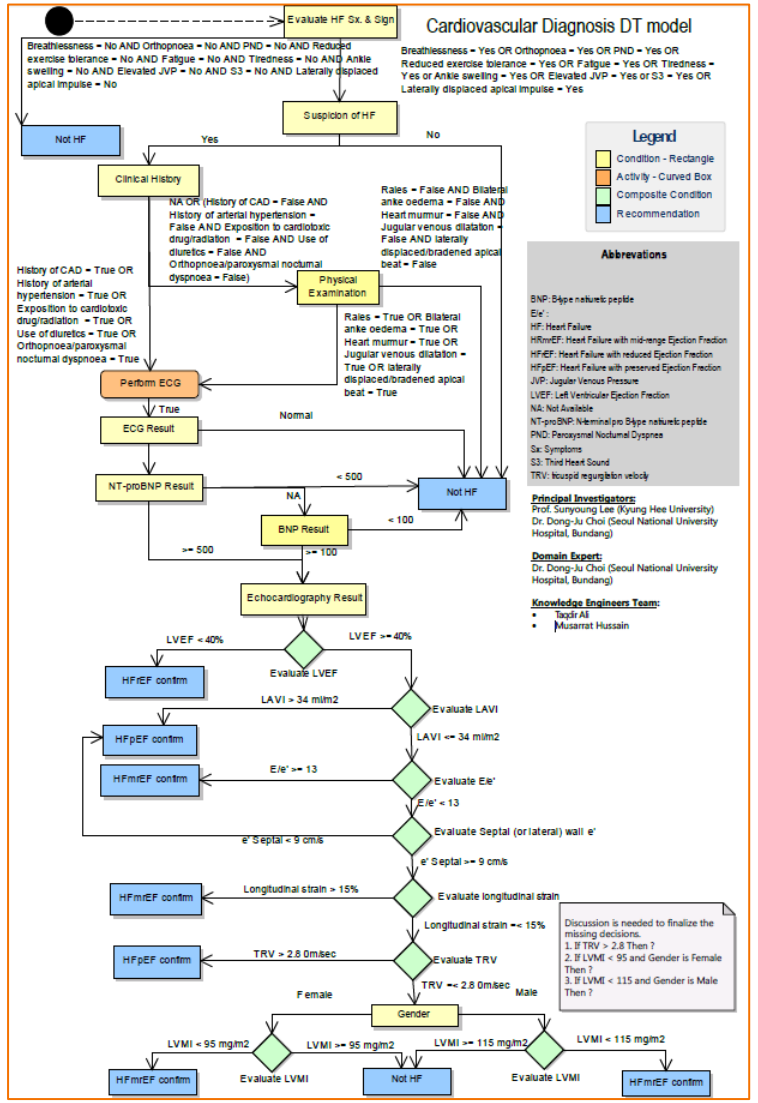
Stage 2: Knowledge Modeling

Mind Map



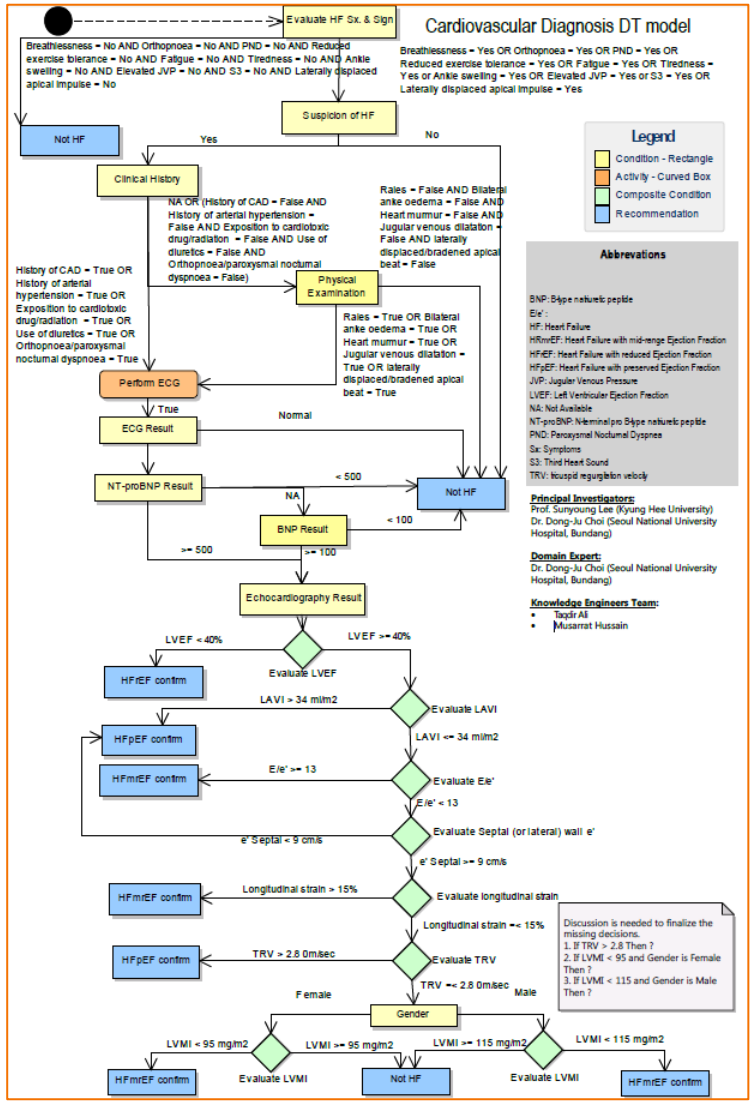
Knowledge Engineer

Decision Tree



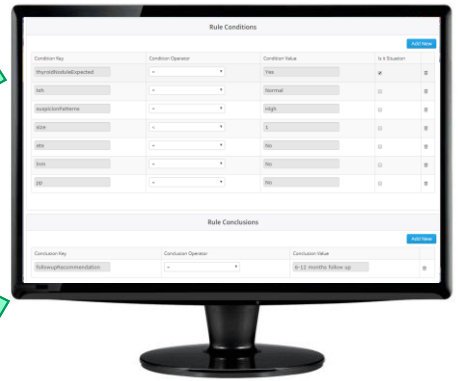
Stage 3: Rule Generation

Decision Tree

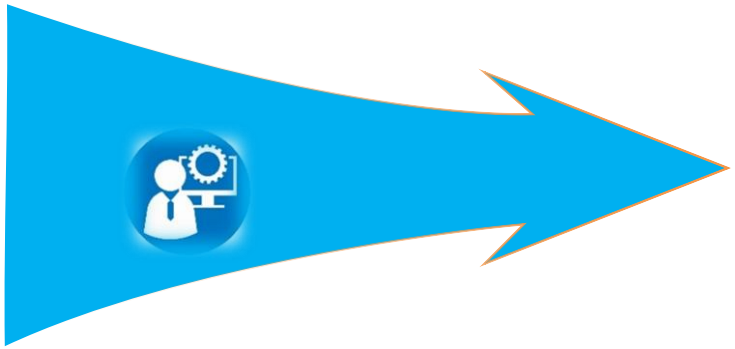


Medical Experts

Intelligent Knowledge Authoring Tool (I-KAT)



Knowledge Engineer



Total Rules: 15409

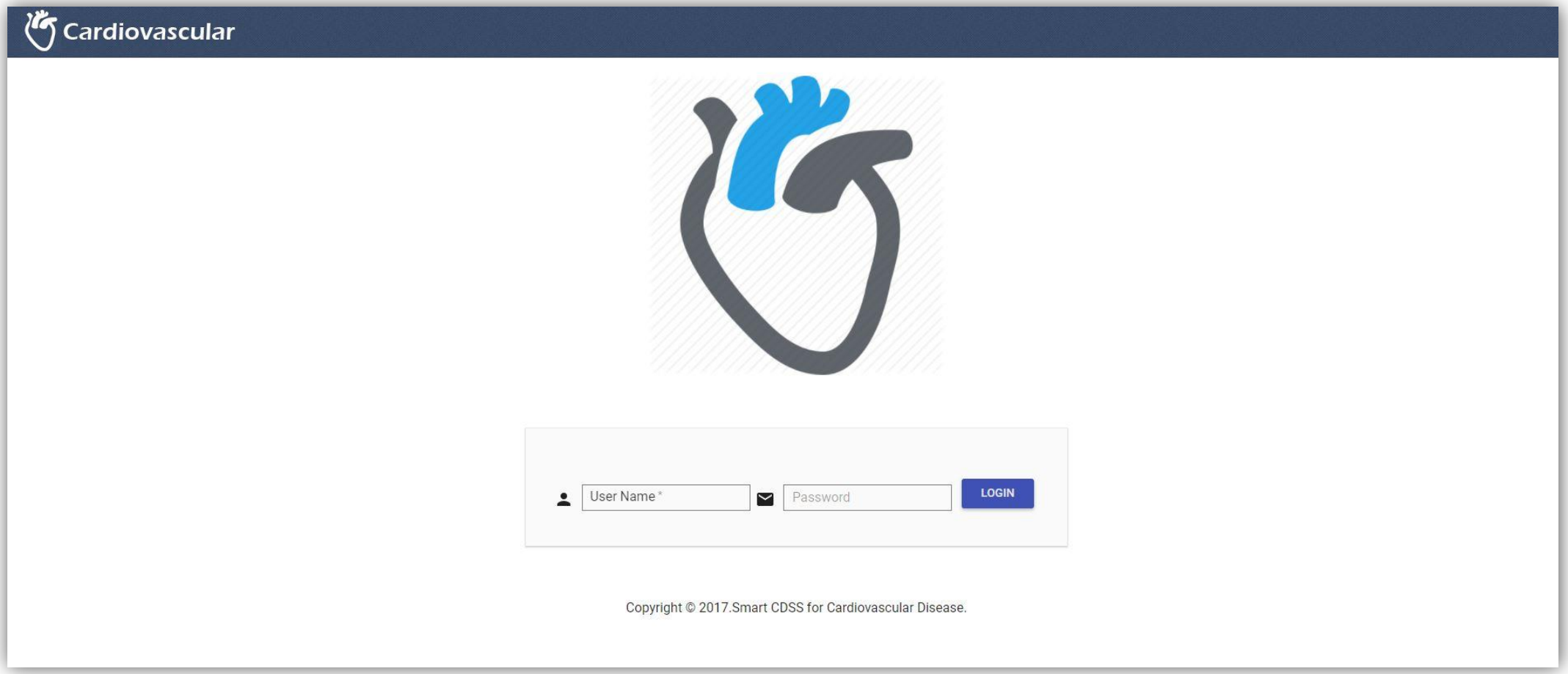
Production Rules

Rule #	RuleTitle	SymptomsAndSigns	ClinicalHistory	PhysicalExam	ECG	NTproBNP	BNP	LVEF
1	CardiovascularRule-1	0	-	-	-	-	-	-
2	CardiovascularRule-2	1	-	-	-	-	-	-
3	CardiovascularRule-3	1	0	-	-	-	-	-
4	CardiovascularRule-4	1	1	0	-	-	-	-
5	CardiovascularRule-5	1	1	1	0	-	-	-
6	CardiovascularRule-6	1	1	1	1	< :125	-	-
7	CardiovascularRule-7	1	1	1	1	-	< :35	-
8	CardiovascularRule-8	1	1	1	1	-	>=:35	<:40
9	CardiovascularRule-9	1	1	1	1	-	>=:35	( ):39 & 50
10	CardiovascularRule-10	1	1	1	1	-	>=:35	>=:50
11	CardiovascularRule-11	1	1	1	1	-	>=:35	>=:50
12	CardiovascularRule-12	1	1	1	1	-	>=:35	>=:50
13	CardiovascularRule-13	1	1	1	1	-	>=:35	>=:50
14	CardiovascularRule-14	1	1	1	1	-	>=:35	>=:50
15	CardiovascularRule-15	1	1	1	1	-	>=:35	>=:50
16	CardiovascularRule-16	1	1	1	1	-	>=:35	>=:50
17	CardiovascularRule-17	1	1	1	1	-	>=:35	>=:50
18	CardiovascularRule-18	1	1	1	1	-	>=:35	>=:50
19	CardiovascularRule-19	1	1	1	1	>= :125	-	<:40
20	CardiovascularRule-20	1	1	1	1	>= :125	-	( ):39 & 50
21	CardiovascularRule-21	1	1	1	1	>= :125	-	>=:50
22	CardiovascularRule-22	1	1	1	1	>= :125	-	>=:50
23	CardiovascularRule-23	1	1	1	1	>= :125	-	>=:50
24	CardiovascularRule-24	1	1	1	1	>= :125	-	>=:50

LAVI	Ee	eSeptal	LongitudinalStrain	TRV	LVMI	Gender	DiagnosisRecommendation	TreeReferencePath
-	-	-	-	-	-	-	Not HF	Cardio_D_1
-	-	-	-	-	-	-	Suspecious HF	Cardio_D_2
-	-	-	-	-	-	-	Not HF	Cardio_D_3
-	-	-	-	-	-	-	Not HF	Cardio_D_4
-	-	-	-	-	-	-	Not HF	Cardio_D_5
-	-	-	-	-	-	-	Not HF	Cardio_D_6
-	-	-	-	-	-	-	Not HF	Cardio_D_7
-	-	-	-	-	-	-	HFrEF confirm	Cardio_D_8
-	-	-	-	-	-	-	HFrmEF	Cardio_D_9
>:34	-	-	-	-	-	-	HF pEF confirm	Cardio_D_10
<=:34	>=:13	-	-	-	-	-	HF pEF confirm	Cardio_D_11
<=:34	<:13	<:9	-	-	-	-	HF pEF confirm	Cardio_D_12
<=:34	<:13	>=:9	> :15	-	-	-	HF pEF confirm	Cardio_D_13
<=:34	<:13	>=:9	=< :15	> :2.80	-	-	HF pEF confirm	Cardio_D_14
<=:34	<:13	>=:9	=< :15	=< :2.80	>= :115	-	HFpEF	Cardio_D_15
<=:34	<:13	>=:9	=< :15	=< :2.80	< :115	Male	Not HF	Cardio_D_16
<=:34	<:13	>=:9	=< :15	=< :2.80	< :95	Female	Not HF	Cardio_D_17
<=:34	<:13	>=:9	=< :15	=< :2.80	>=:95	Female	HFpEF	Cardio_D_18
-	-	-	-	-	-	-	HFrEF confirm	Cardio_D_19
-	-	-	-	-	-	-	HFrmEF	Cardio_D_20

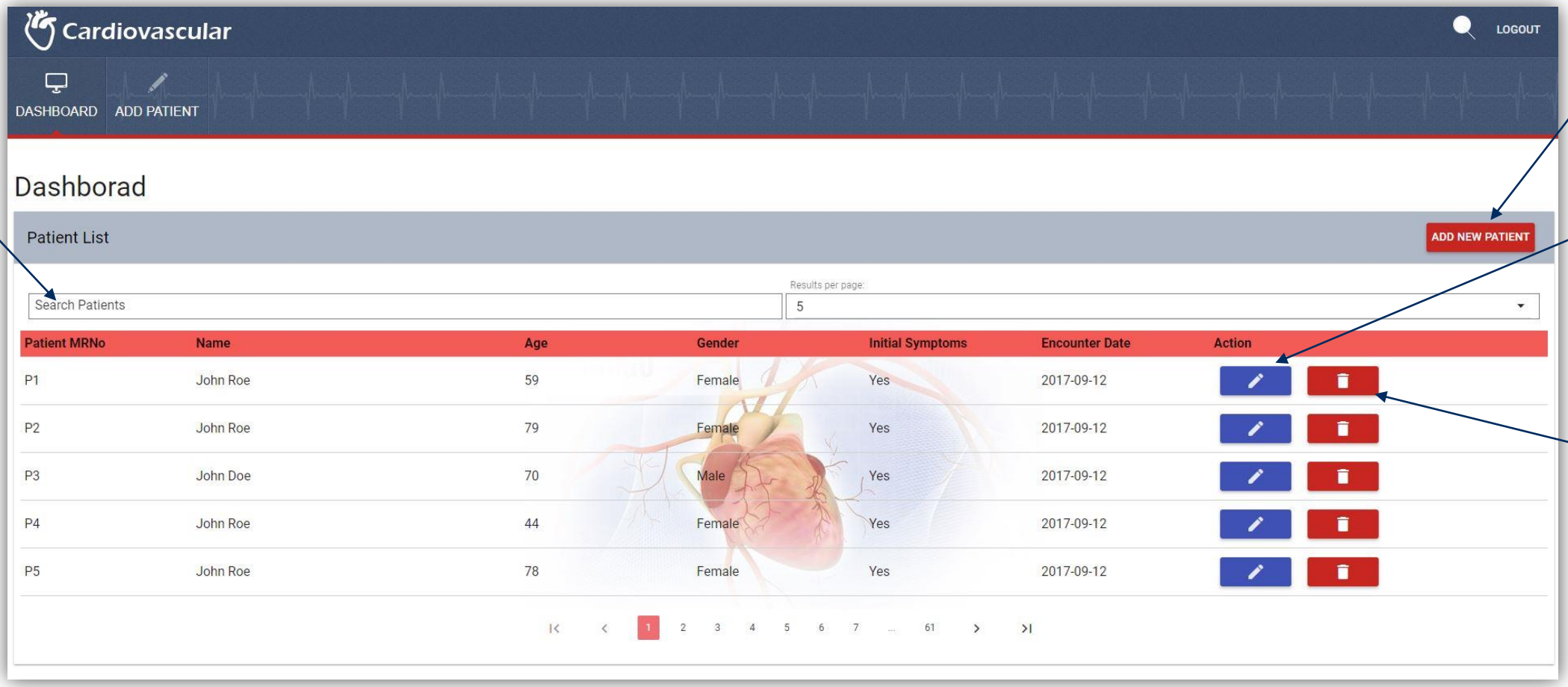
Stage 4: Implementation (Login Screen)

Login Screen: Only authorized physicians can be logged in to the system



Stage 4: Implementation (Dashboard)

Dashboard: Shows all the patient data from EMR and EHR systems



Stage 4: Implementation (Patient Detail Screen)

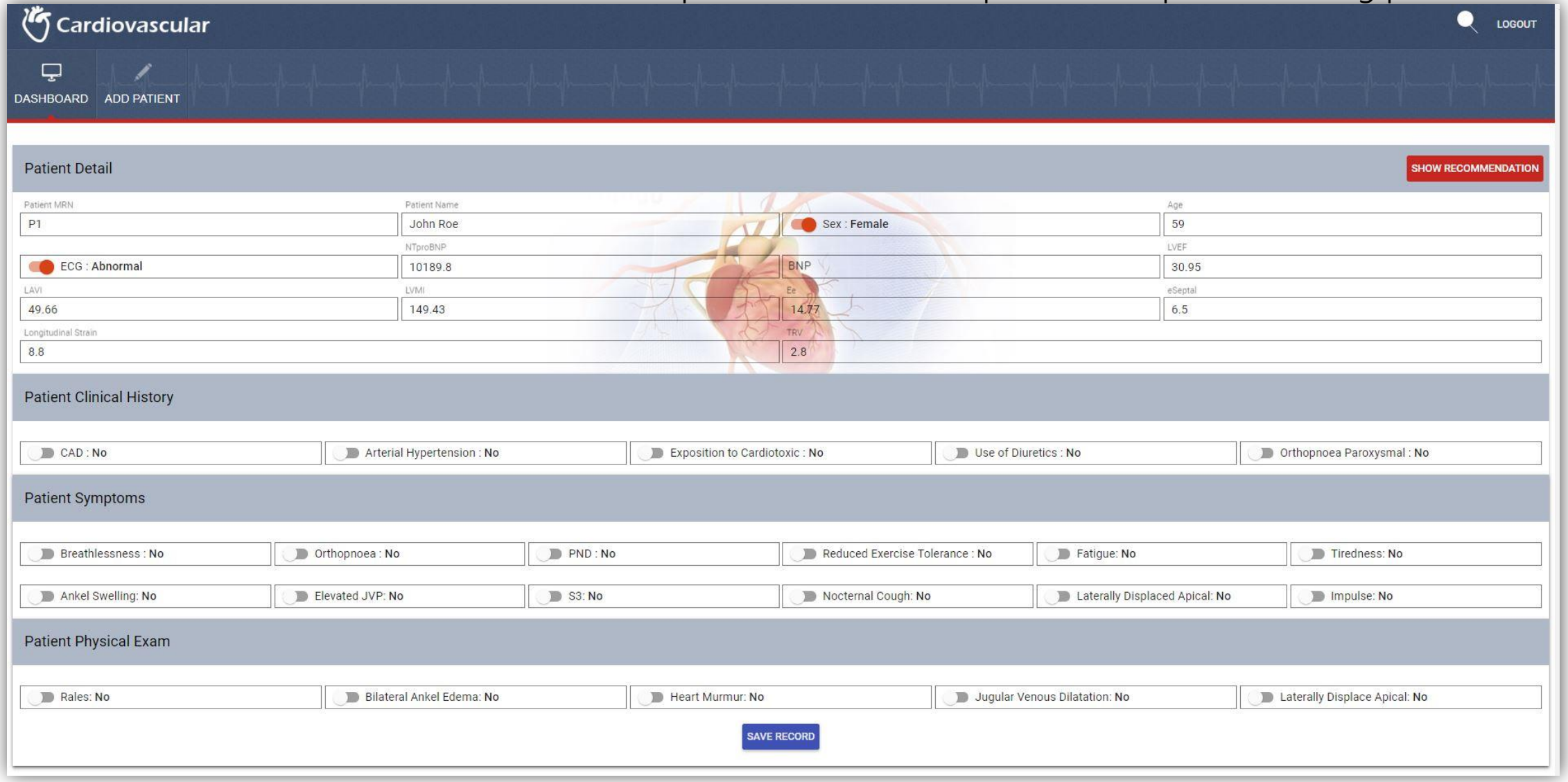
Patient Detail Screen: Shows all detail of patient to add new patient of update existing patient

Patient Information And Cardio Information

Patient clinical History

Patient Symptoms

Patient Physical exam information



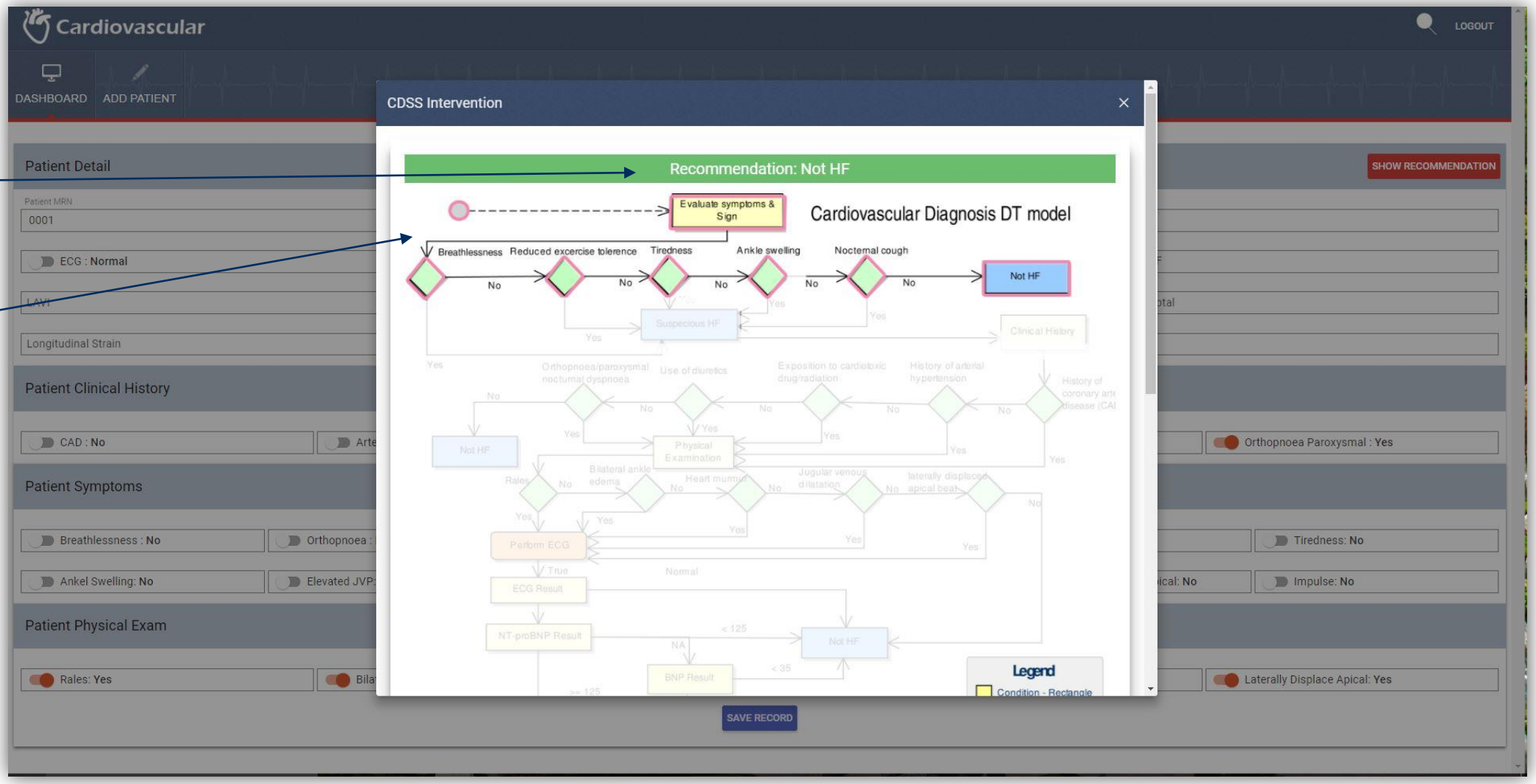
Stage 4: Implementation (CDSS Intervention)

CDSS Intervention: Shows the recommendation of a patient based on patient profile and symptom

The decision comes from knowledge base

Final Decision

Knowledge Rule triggered



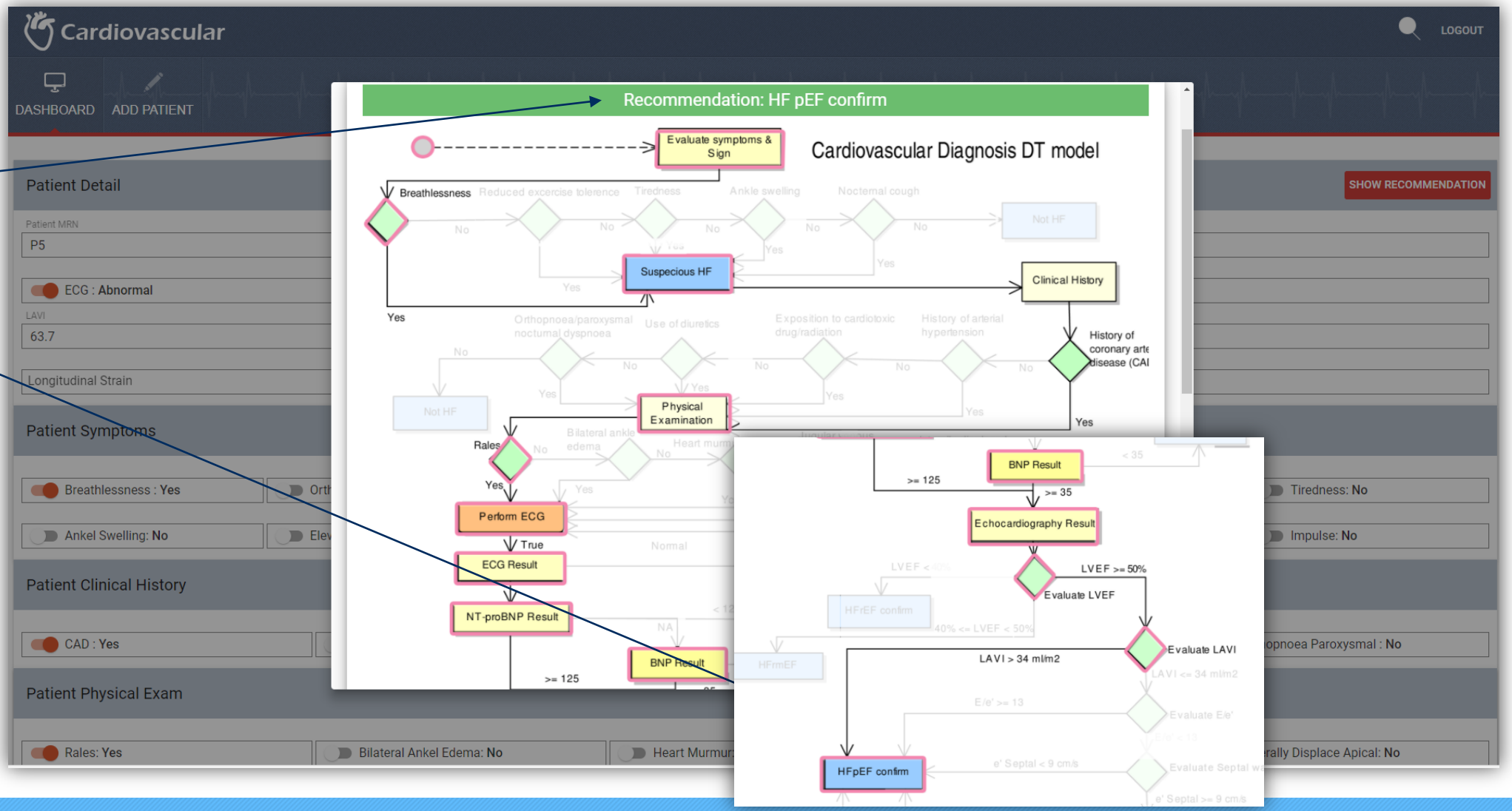
Stage 4: Implementation (CDSS Intervention)

CDSS Intervention: Shows the recommendation of a patient based on patient profile and symptom

The decision comes from knowledge base

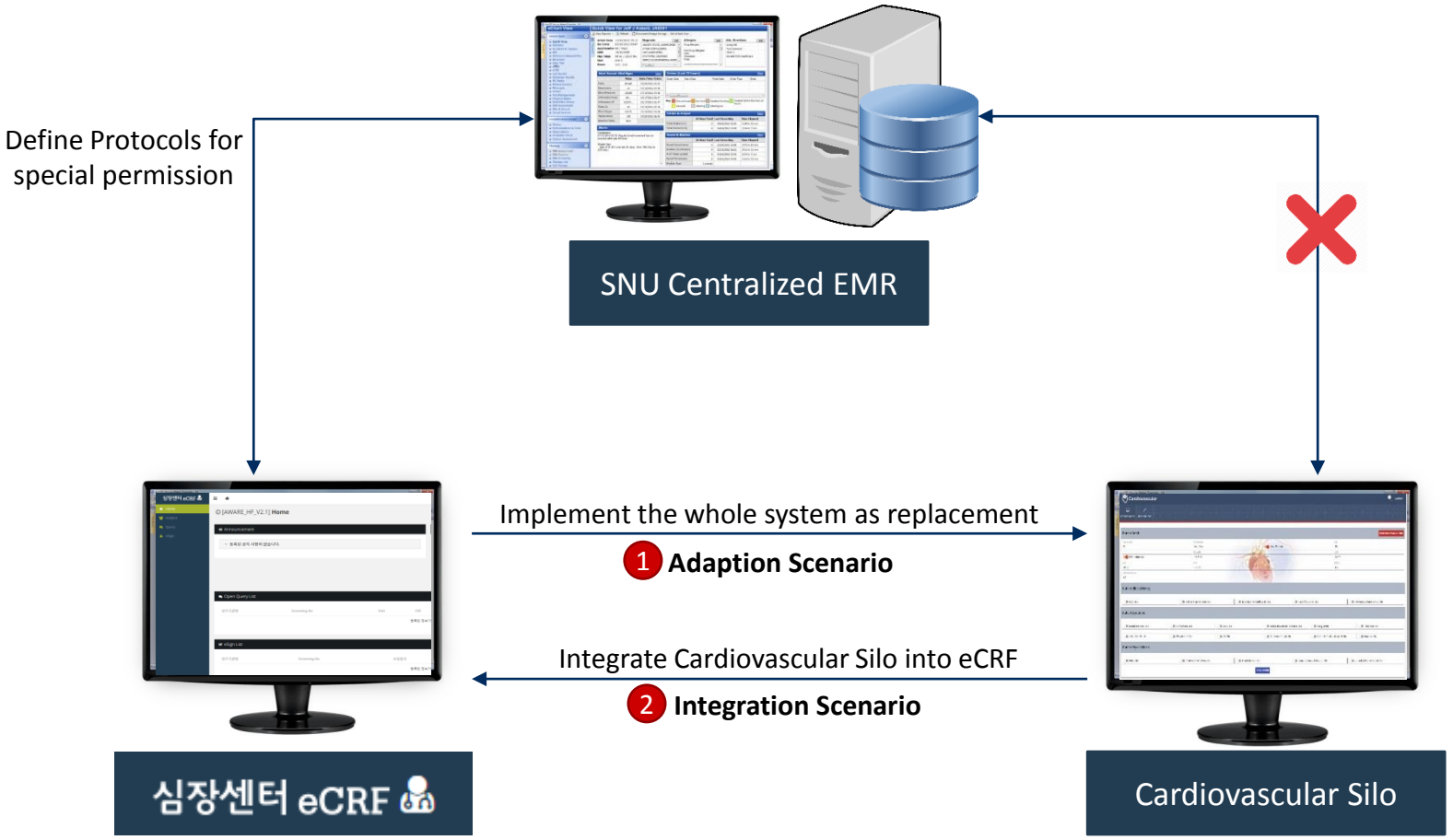
Final Decision

Knowledge Rule triggered



Stage 4: Implementation (CDSS Integration)

- Integration with EMR system
  - According to Government policy, we cannot integrate our system with SNU EMR system
  - We will define some protocol to merge our developed Silo with their existing System.



Stage 4: Implementation (CDSS Integration)

1 Adaption Scenario

심장센터 eCRF

- Required Efforts
  - System analysis
  - System requirement understandability
  - System Requirement Specification
  - System Design
  - Data base Design
  - System GUI Design and Development
  - CRUD Web services Design and Development
  - CDSS intervention web services integration
  - System Testing and Development
- Required Resources
  - At least 3 developers are required
  - At least 3 – 4 months are required

2 Integration Scenario

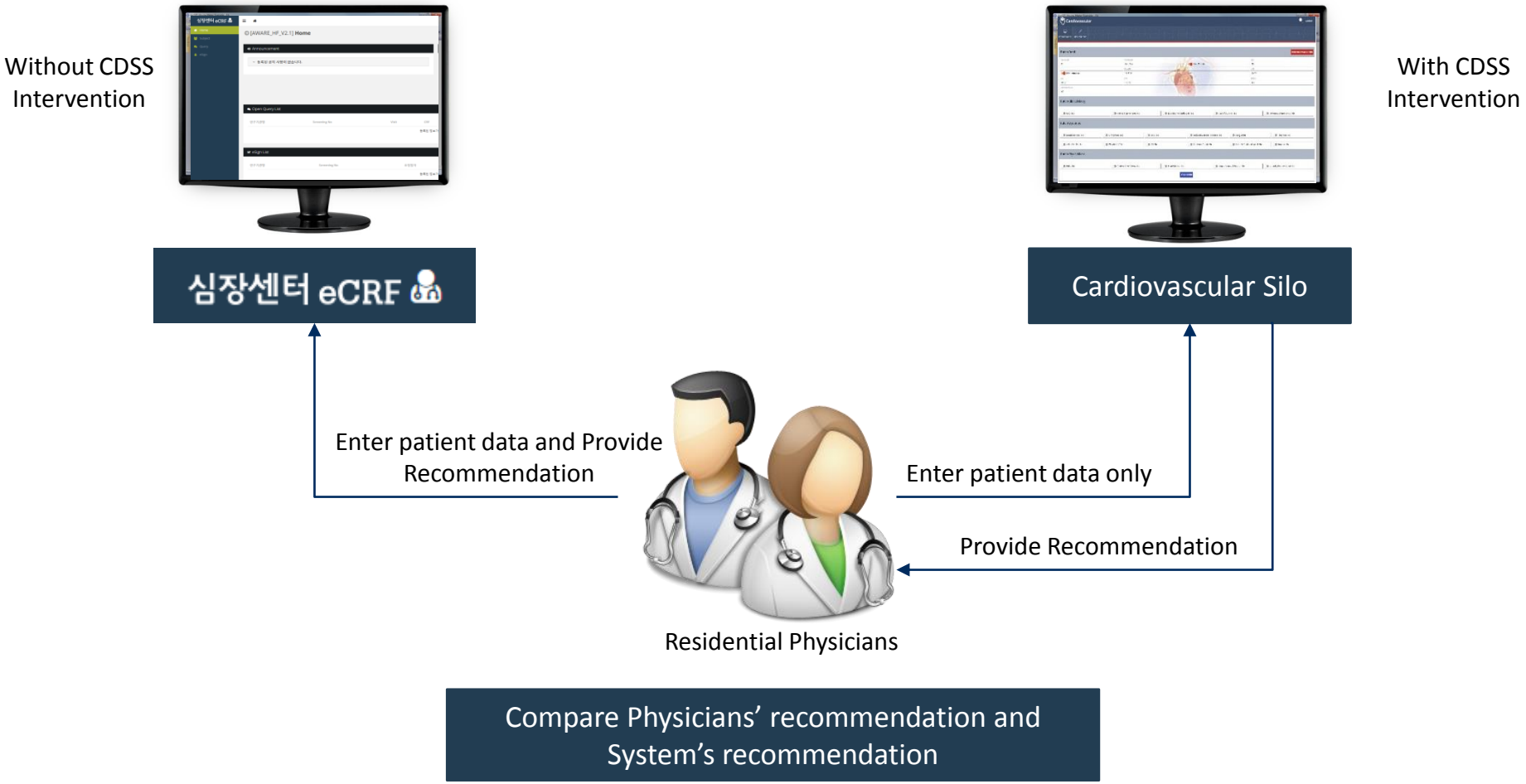
Cardiovascular Silo

- Feasibility Study
  - eCRF source code available at SNU?
    - No – Scenario 2 not feasible, Scenario 1 is considerable.
    - Yes – Scenario 2 is feasible
  - Development Team Availability at SNU?
    - Yes – Collaboratively work
      - We will provide CDSS web services
      - SNU Team will consume web services
    - No – We will integrate Silo into eCRF
- Required Efforts
  - Analyze CDSS intervention locations
  - We have already developed CDSS Web services
  - Need to develop only consumer of CDSS services
- Required Resources
  - 1 developer is required
  - 10 – 15 days are required

Stage 5: Evaluation (By Physicians)

IMP V1.0_KnowledgeModeling_V0.2_20170925_Taqdir Ali

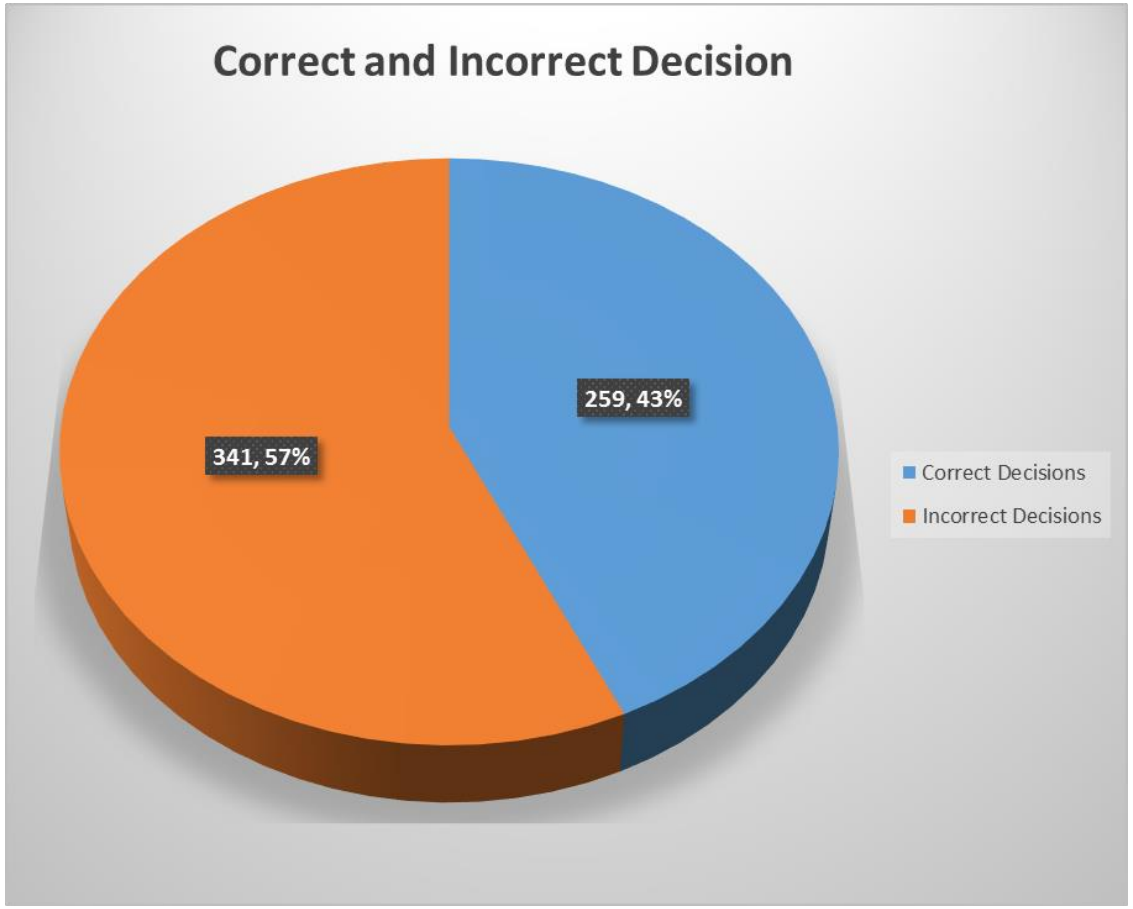
- System Accuracy
  - The accuracy of the system will check by Residential Doctors in Cardiovascular Department of SNU.



Stage 5: Evaluation (Initial Evaluation)

IMP V1.0_System Integration_V0.5_20171127_Taqdir Ali

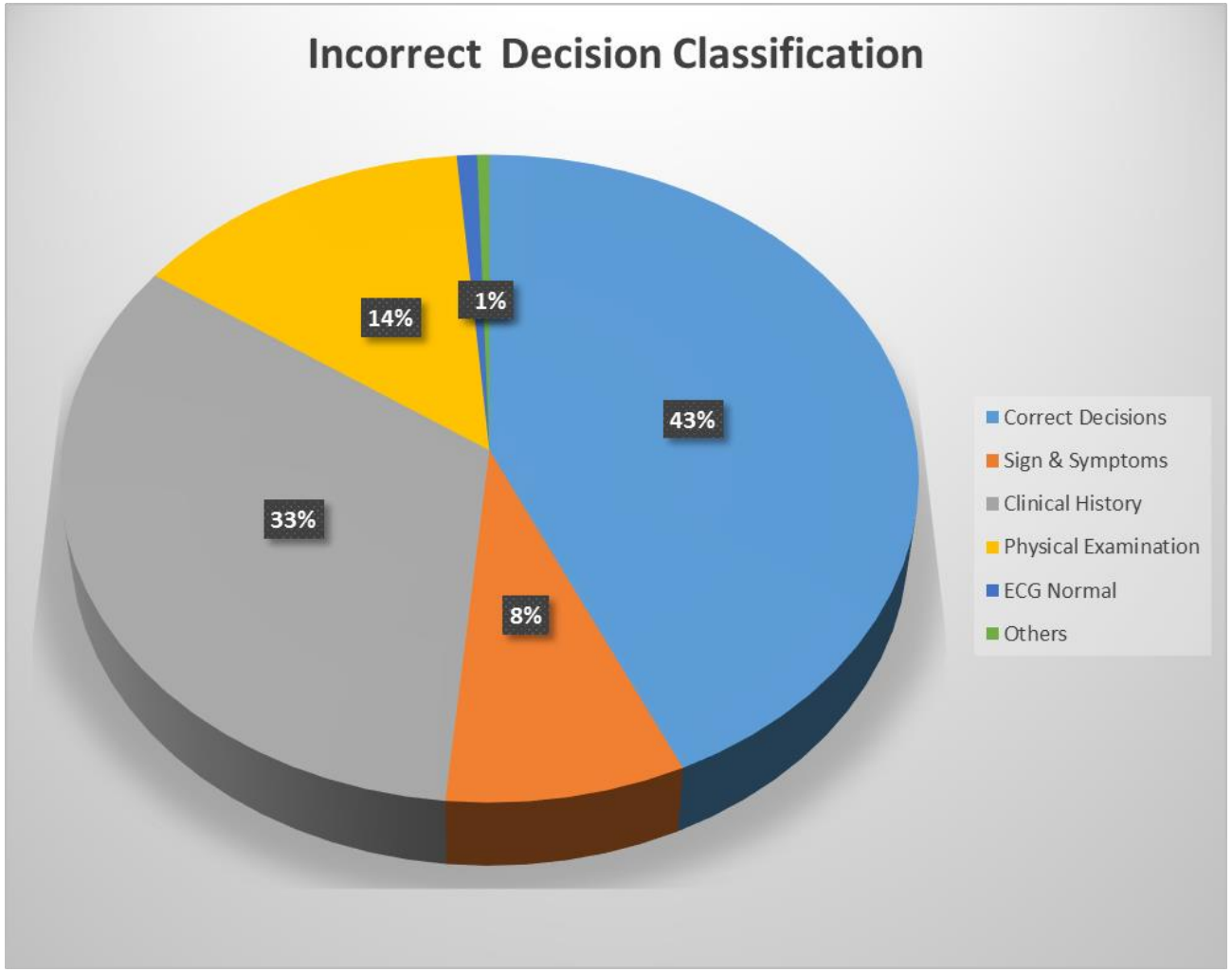
- Total Number of Rules 1329 during first evaluation
- Analysis of 600 Patient Data
  - Physicians provides 600 patient data with already given decisions.
  - Generate recommendations using developed Silo for 600 patients.
  - Analyzed and compared the decisions of physicians and Silo



Stage 5: Evaluation (Initial Evaluation)

IMP V1.0_System Integration_V0.5_20171127_Taqdir Ali

- Incorrect decision Classification
  - Correct = 259
  - Sign & symptoms = 50
  - Clinical History = 199
  - Physical Examination = 84
  - ECG Normal = 5
  - Others = 3



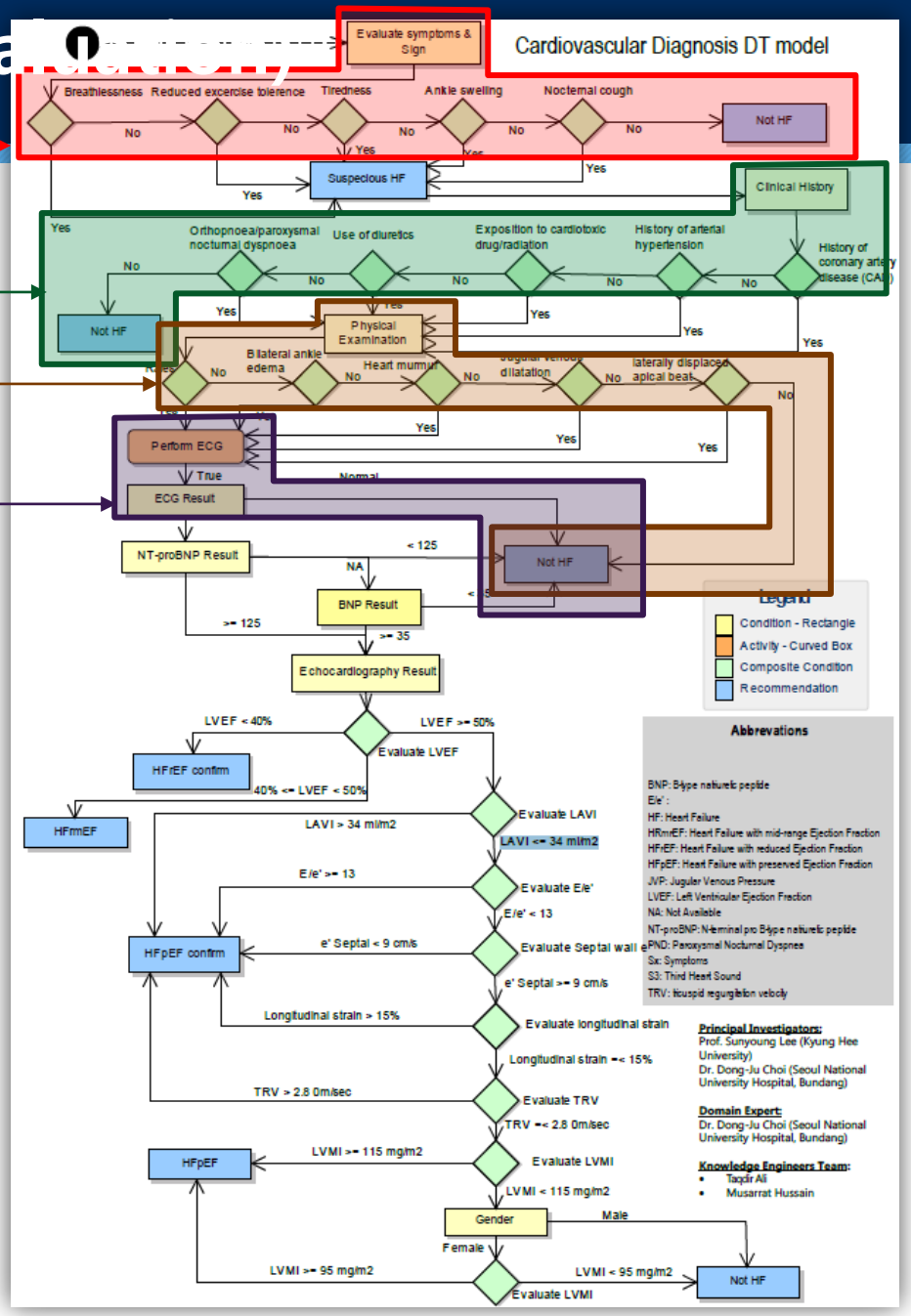
Stage 5: Evaluation (Initial Eva[illegible])

Sign & Symptoms halts 50 Patients

Clinical History halts 199 Patients

Physical Exam halts 84 Patients

ECG Normal halts 5 Patients

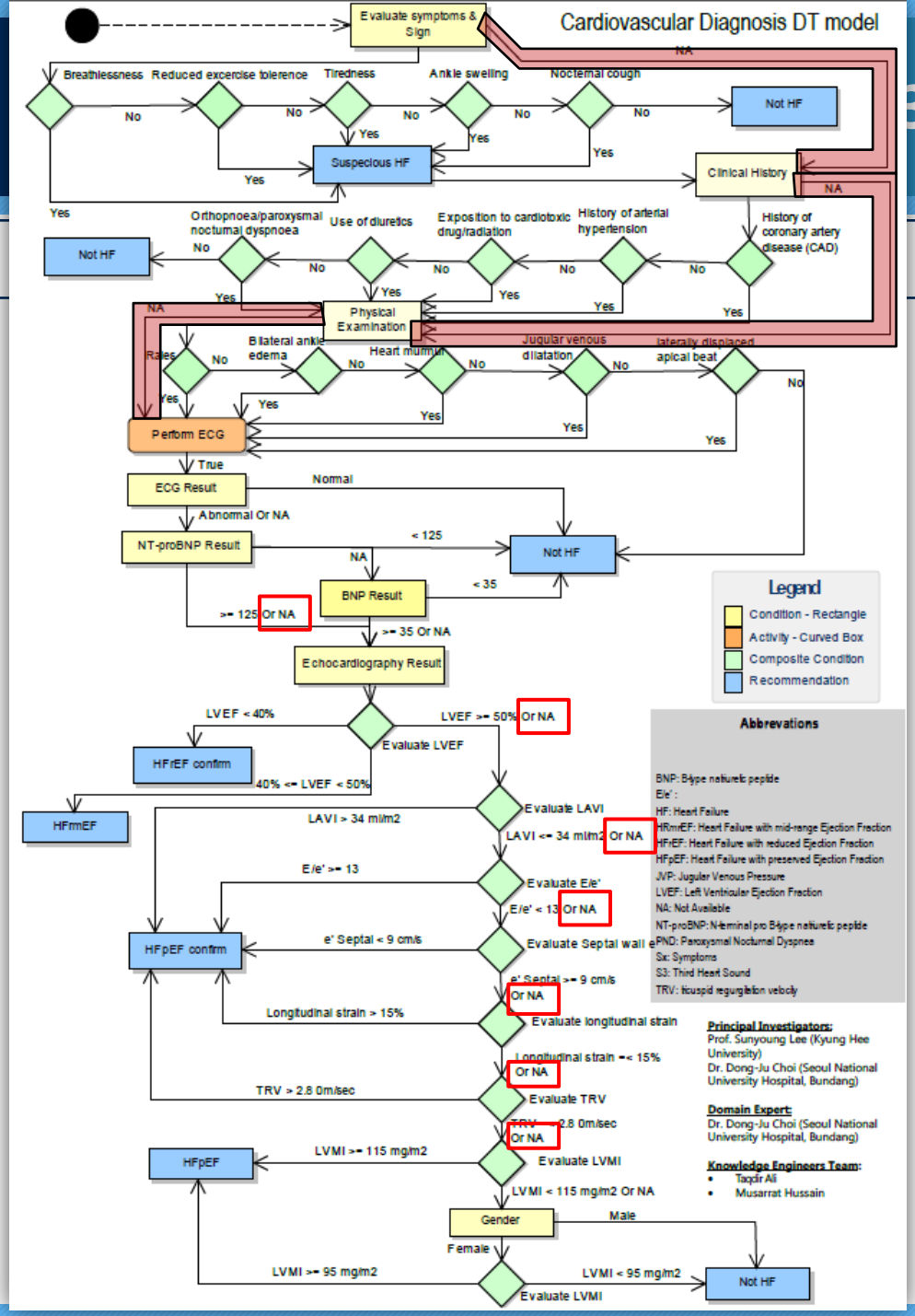


When the issues of aforementioned halting paths will fix then the system accuracy will be greater than 98%.

Stage 5: Evaluation (Correction in DT)

IMP V1.0_System Integration_V0.5_20171219_Taqdir Ali

- Changes in Decision Tree
  - Before, the decision tree was halting the decision for the Not Available values of attributes.
  - Changed the decision tree for unknown values.
  - Due to this change for each path, number of rules drastically increased from 1309 to 15409.
    - The number of rules increased due to combination formula for each Not Available path.
  - 15409 rules entered to the knowledge base in more than 4 days (Approximately 98 – 100 hours).
  - Generated Recommendation for 600 patients from 15409 rules in 1 and half day (Approximately 35 hours)



Stage 5: Evaluation (Correction in Patient Data)

IMP V1.0_System Integration_V0.5_20171219_Taqdir Ali

Age	Gender	Symptoms & Sign (If 1 or more=1, NO=0	Clinical History (If 1 or more=1, NO=0	Physical Exam (If 1 or more=1, NO=0	ECG (normal=0, abnorma=1)	NT-proBNP	BNP	LVEF	LAVI	LVMI	E/e'	e' septal	TRV	Longitudinal strain(GLS)	Expert Decision	CDSS Decision
76	M	0	0	0	1	4014.9		51.11	61.01	110.34	7.14	5.6	2.3	17.4	HFpEF	Not HF
57	F	0	0	0	1	3266.3		46.79	24.34	135.88	12.4	7.5			HFmrEF	Not HF
78	F	0	0	0	1	>35000		29.36	54.74	115.04			3.3	7.8	HFrEF	Not HF
77	F	0	0	0	1	14666.3		49.8	33.04	62.22	15	2.8			HFmrEF	Not HF
65	M	0	0	0	1	2928.7		44.35	28.41	106.53	10.3	6.7	2.2	8.9	HFmrEF	Not HF
74	M	0	0	0	1	3638.4		53.62		109.61	10.89	4.5	2.3	14.7	HFpEF	Not HF
57	M	0	0	0	1	2840		51.53	85.15	229.82	17.92	4.8	3.1		HFpEF	Not HF
68	M	0	0	0	1	1289		55.24	29	120.32	15.92	4.9	2.68	11.9	HFpEF	Not HF
61	F	0	0	0	1	2064.6		47.95	25.99	104.01	8.86	3.5			HFmrEF	Not HF
73	F	0	0	0	1	729.2		40.74	40.3	88.34	15.83	4.8	2.1		HFmrEF	Not HF
87	M	0	0	0	1	1017		44.59	28.4	86.63	16.32	3.8		8.1	HFmrEF	Not HF
63	F	0	0	0	1	8253.5		37.93	60.86	185.74	26.83	4.1	2.8	9.1	HFrEF	Not HF
64	M	0	0	0	1	7981.7		59.15	32.97	89.2	16.67	6.9		12	HFpEF	Not HF
52	M	0	0	0	1	10358.2		17.72	46	139.26	23.75	3.2	2.7		HFrEF	Not HF
76	M	0	0	0	1	>35000		32.84	58.33	122.7	23.72	4.3	3.2	9.2	HFrEF	Not HF
76	M	0	0	0	1	10231.6		60.66	41.94	147.45	23.52	5.4	3	15.9	HFpEF	Not HF
30	F	0	0	0	1	447.8		48.19	30.26	71.61	9.21	10.1	1.9	14.4	HFmrEF	Not HF
77	F	0	0	0	1	10274.1		60		70.13	8.72	3.9	2.1		HFpEF	Not HF
22	M	0	0	0	1	3218.2		52.05	27.01	122.59	6.58	11.1	2.4		HFpEF	Not HF

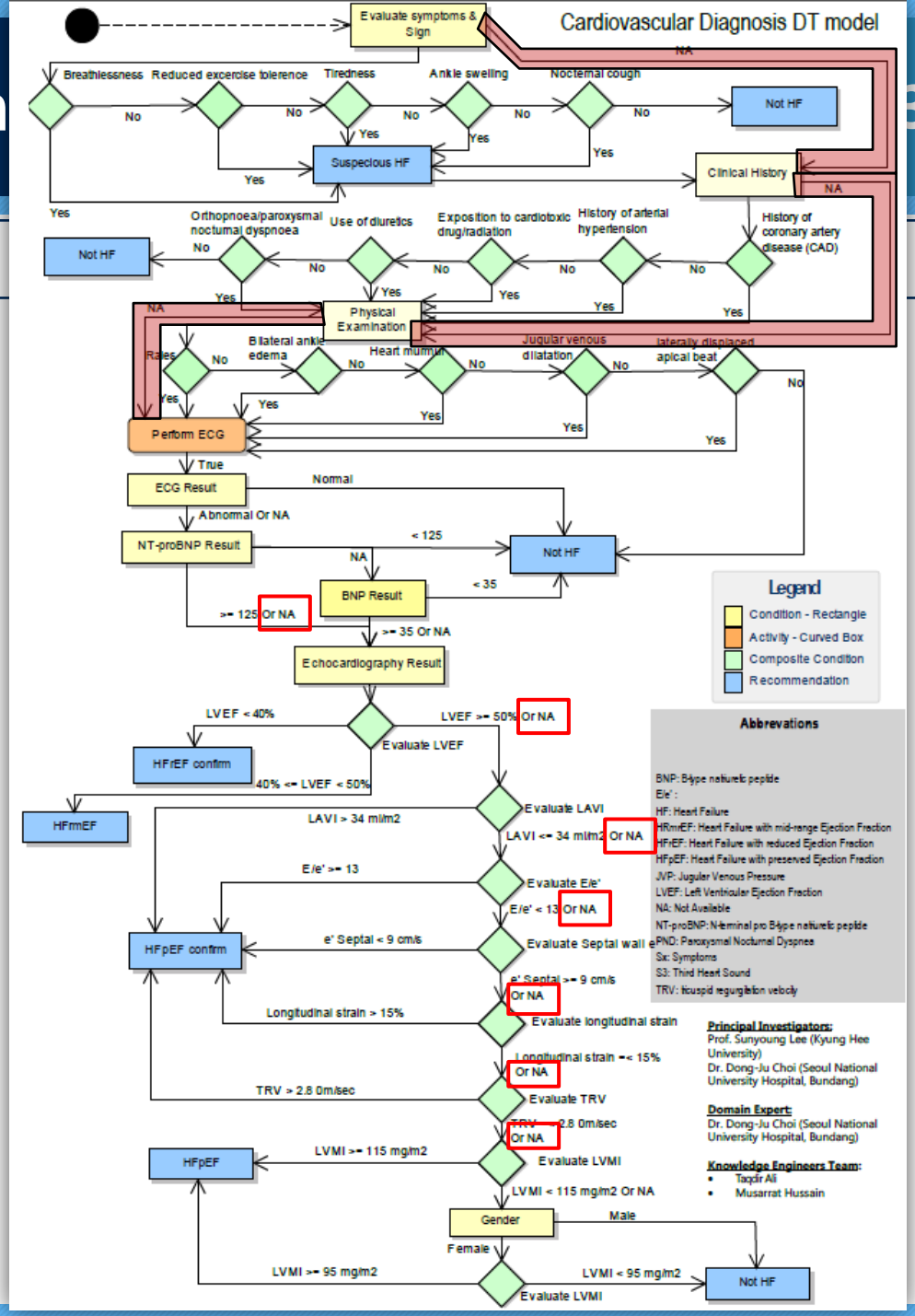
- Incorrect decision Classification
  - Sign & symptoms = 50
  - Clinical History = 199
  - Physical Examination = 84
  - ECG Normal = 5
  - Others = 3

- Issue in Patient Data
  - For Symptoms & Sign, Clinical History, Physical Exam, and ECG
  - If 1 or more then value = 1 (yes) and value = 0 (No)
  - What about Not Available?
  - Whenever the value is zero in one of the above attributes then patient has Not Heart Failure. And no need to check other attributes.
  - Conclusion is that, the values for the above attributes is not zero, it is Not Available.

Stage 5: Evaluation (Second Evaluation

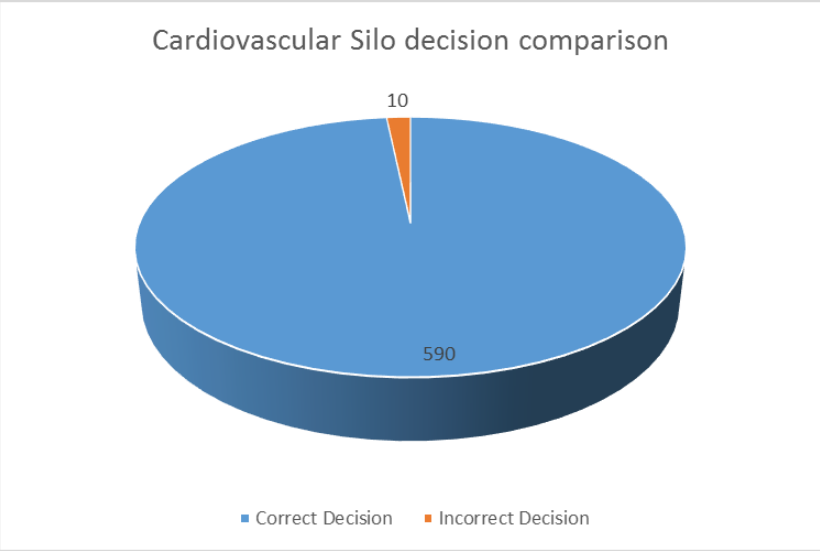
IMP V1.0_System Integration_V0.5_20171229_Taqdir Ali

- Analyzed 600 patients with new set of Rules (15409) based on Modified Decision Tree
  - Correct Decision = 590
  - Incorrect Decision = 10
  - No Decision = 0
  - Overall Accuracy = 98.3%

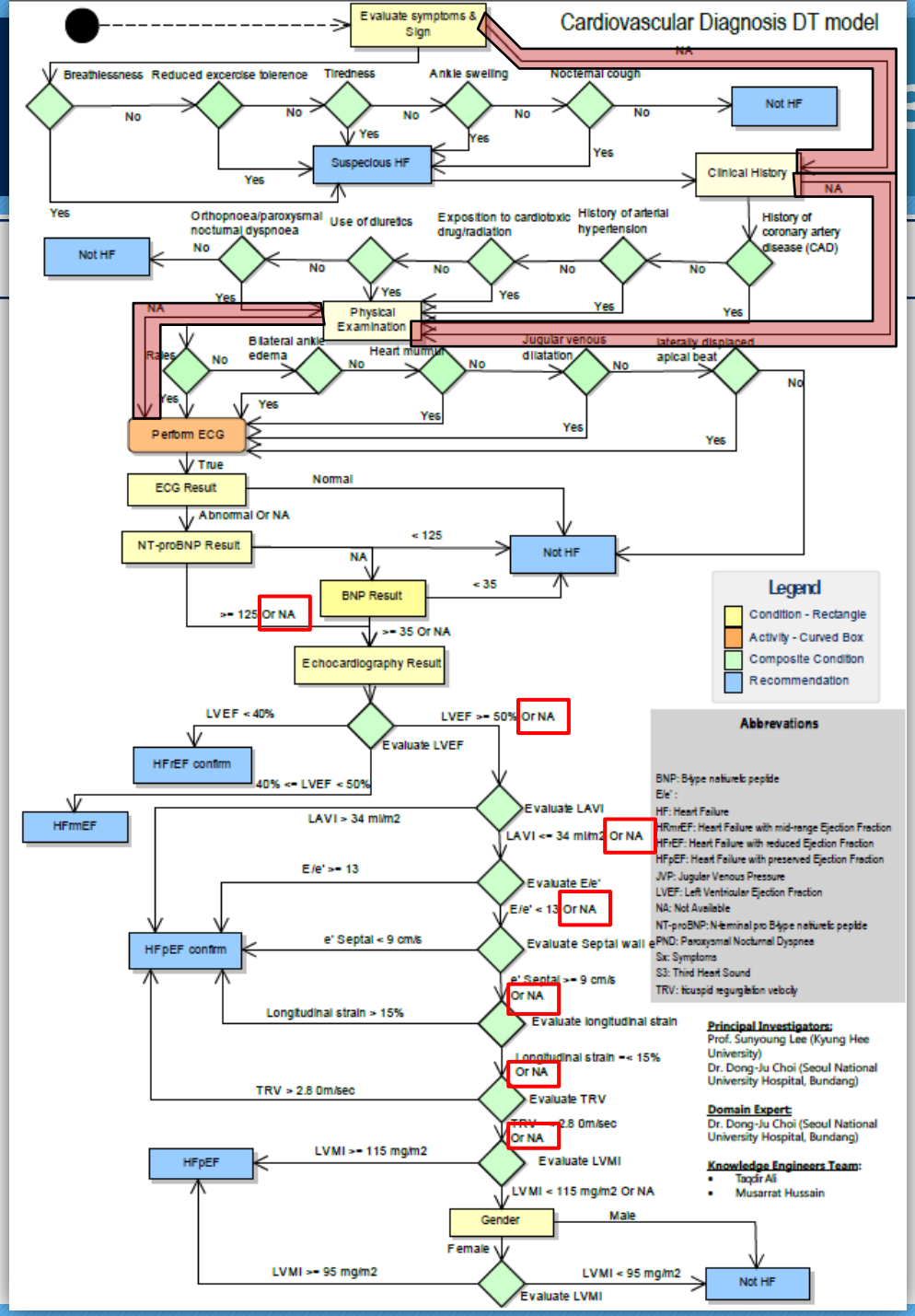


Cardiovascular Silo: Meeting Minutes

IMP V1.0_System Integration



- Incorrect Decision = 10
  - Reasons:
  - For 7 patients, ECG = 0, we changed to Not Available
  - For 3 patient, system generates right decision based on data, but physicians already given different decision.

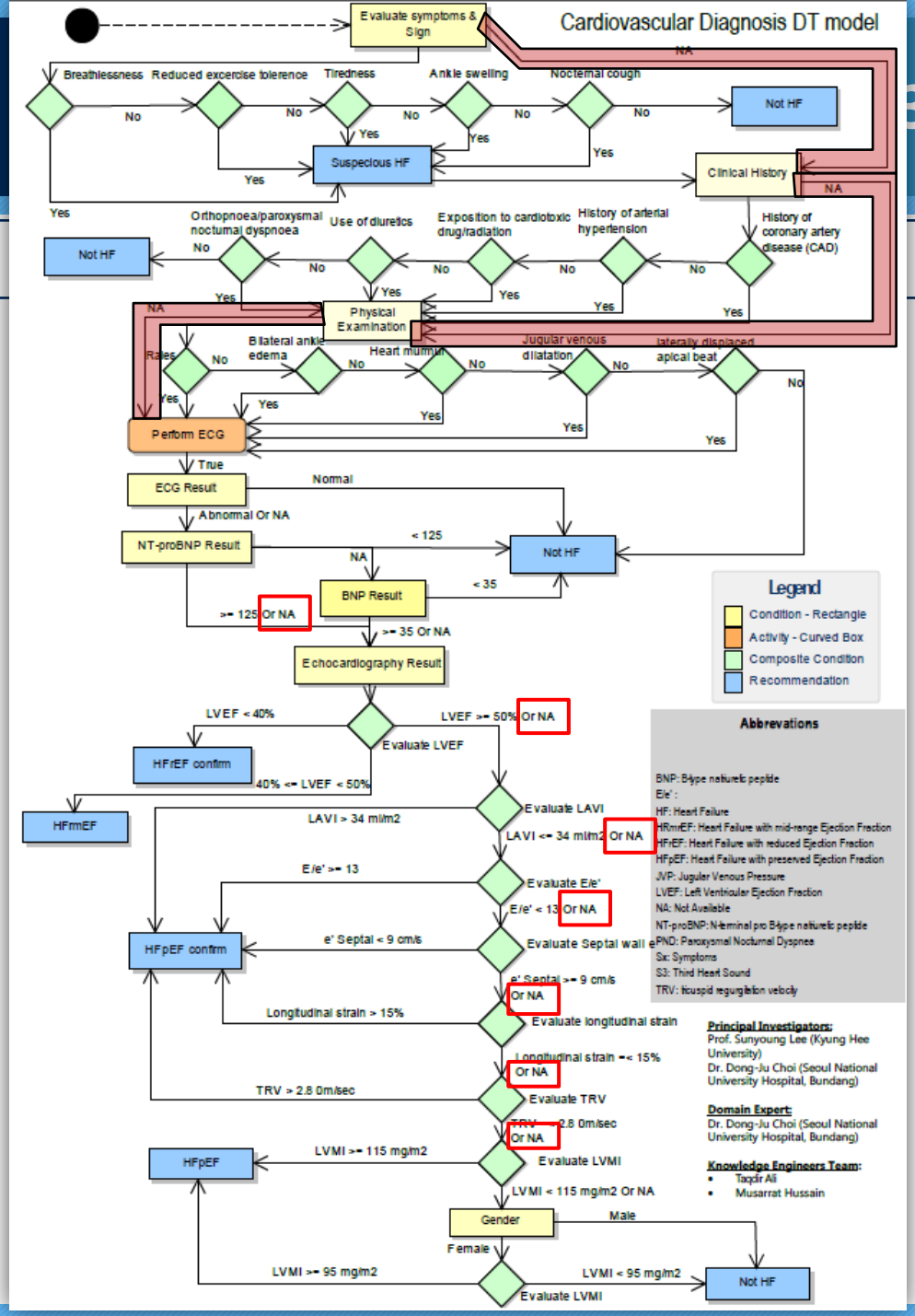


Cardiovascular Silo: Meeting Minutes

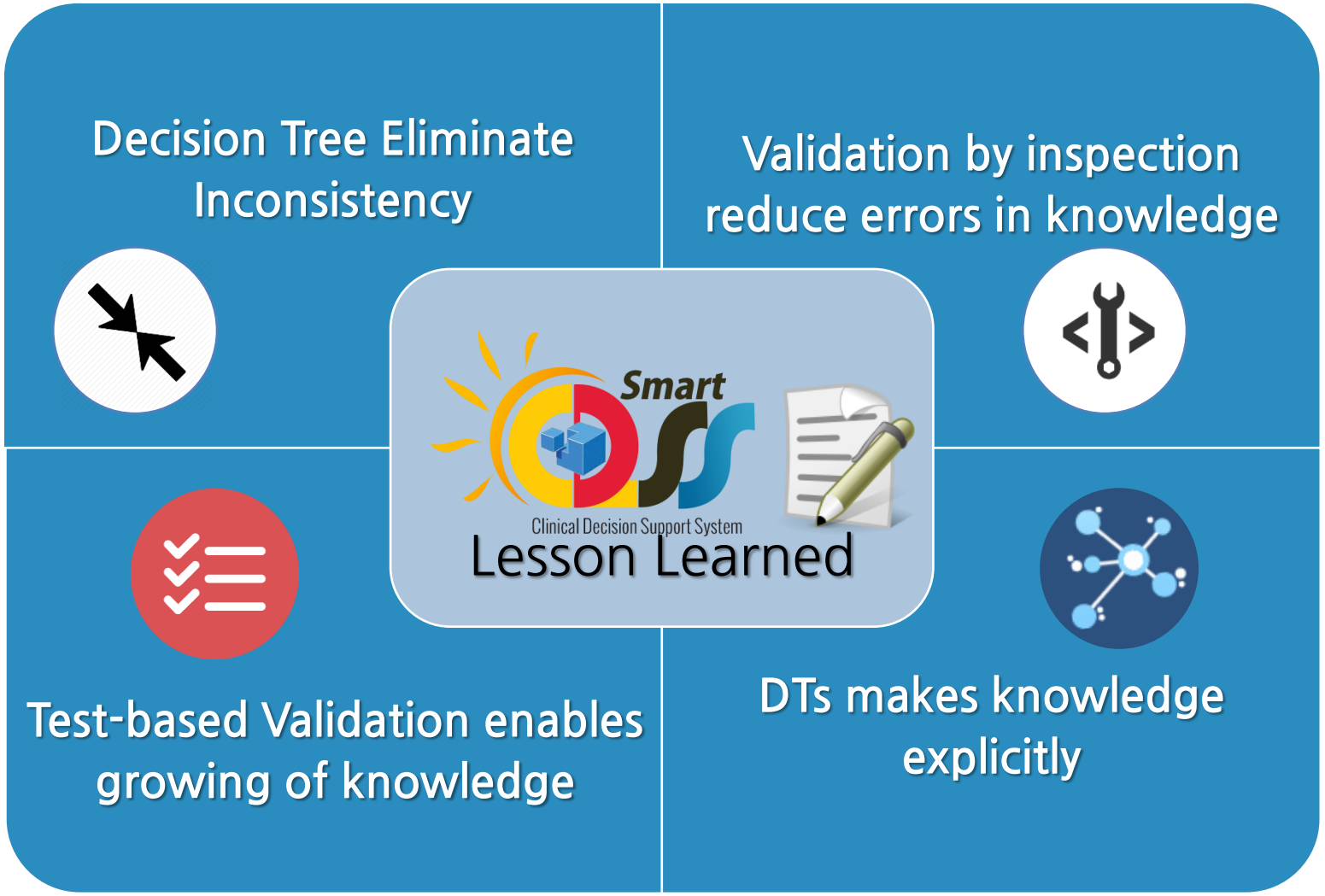
IMP V1.0_System Integration

- True Positive, TP = 590
- False Positive, FP = 10

- Accuracy = (TP + TN)/(TP+TN+FP+FN)
- Accuracy = (590 + 0)/(590+0+10+0)
- Accuracy = 0.983
  - 98.3%



Lesson Learned



Thanks

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